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GROUND-WATER POLLUTION IN THE MIDDLE AND LOWER SOUTH PLATTE RIVER BASIN OF COLORADO

Federal Water Pollution Control Administration
Denver, Colorado

July 1967

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GROUND-WATER POLLUTION IN THE MIDDLE AND LOWER SOUTH PLATTE RIVER BASIN OF COLORADO

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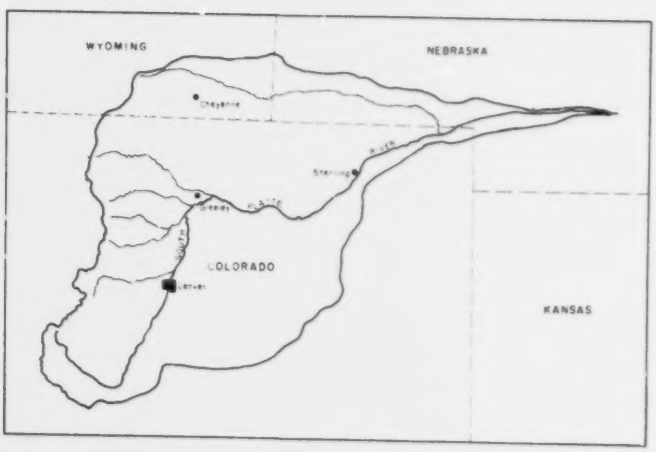

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U. S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
South Platte River Basin Project
Denver, Colorado

JULY 1967

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Federal Water Quality Administration
South Platte River Basin Project
Report (PR-no.)
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GROUND-WATER POLLUTION
IN THE
MIDDLE AND LOWER SOUTH PLATTE RIVER BASIN
OF COLORADO

U. S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration
South Platte River Basin Project
Denver, Colorado

JULY 1967

SOUTH PLATTE RIVER BASIN PROJECT
Federal Water Pollution Control Administration

Background and Objectives

On July 18, 1963, the Governor of Colorado requested the Secretary of Health, Education, and Welfare to assist the State in determining sources of pollution and quality of waters of the South Platte River Basin within the State of Colorado.

The First Session of the Conference in the matter of Pollution of the South Platte River Basin was held in Denver, Colorado, on October 29, 1963, under the provisions of the Federal Water Pollution Control Act (33 U.S.C. 466 et seq.). It was recommended at this Conference that a study would be undertaken by facilities of the U. S. Public Health Service, now the Federal Water Pollution Control Administration, U. S. Department of the Interior. Findings and recommendations from this study were to lead to a program of pollution abatement to be developed jointly by the South Platte River Basin Project and the Colorado State Department of Public Health.

The long-range goals and objectives of the Project are as follows:

1. Determine the legitimate water uses and locate the sources of pollution having an adverse effect on those uses.

2. Through field investigations determine the physical, chemical, and biological responses of the River to pollution and evaluate the previously located sources of pollution with respect to the conditions in the River.

3. Compute the waste load reductions necessary to obtain desired water quality and recommend water quality control measures needed to effect the desired waste load reductions.

4. Recommend remedial time schedules for pollution abatement action.

The Second Session of the Conference was held in Denver, Colorado, on April 27-28, 1966, under the provisions of the Federal Water Pollution Control Act, as amended. At this Conference a report was made by the Project which included specific recommendations and time schedules for pollution abatement in the Denver Metropolitan area and for the sugar beet and cattle feedlot industries throughout the Basin. Specific water quality objectives were recommended for the South Platte River and its major tributaries.

1-f

The Second Session of the Conference was reconvened in Denver, Colorado, on November 10, 1966. At this Conference a pollution abatement schedule was adopted by the Colorado Water Pollution Control Commission and the Federal Water Pollution Control Administration.

Organization

The South Platte River Basin Project consists of engineering and associated professional and clerical personnel. The Project Headquarters offices are located in Denver, Colorado. The Project is administratively attached to the Missouri Basin Region, Federal Water Pollution Control Administration, U. S. Department of the Interior, Kansas City, Missouri.

TABLE OF CONTENTS

	Page
LIST OF TABLES	iv
LIST OF FIGURES	iv
ACKNOWLEDGMENTS	vi
SUMMARY AND CONCLUSIONS	vii
RECOMMENDATIONS	ix
INTRODUCTION	1
AREA OF INVESTIGATION	1
GEOLOGY AND OCCURRENCE OF GROUND WATER	2
Crystalline Rock Aquifers	2
Artesian Aquifers	2
Tertiary Aquifers	3
Valley-Fill Aquifers	4
Dune Sand Deposits	6
USE OF GROUND WATER	7
CHEMICAL QUALITY OF GROUND WATER	7
Valley-Fill Aquifers	7
Other Aquifers	11
GROUND-WATER POLLUTION	12
Saline Water	12
Alkyl Benzene Sulfonate	16
Nitrate	17
Other Contaminants	21
GLOSSARY	22
BIBLIOGRAPHY	23
APPENDIXES	28
APPENDIX A - System of Numbering Wells and Sampling Points	29
APPENDIX B - Chemical Analyses of Water	30
APPENDIX C - Chemical Analyses of Water Associated with Petroleum-Bearing Formations	36
APPENDIX D - Reported Quantities of Water Produced and Injected in Oil and Gas Fields in 1966	38

LIST OF TABLES

Number	Title	Page
I	Use of Water Wells	8
II	Municipal Water Systems Supplied by Wells	9
III	Summary of Chemical Quality of Water Associated with Petroleum-Bearing Formations	13
IV	Nitrate Concentrations in Water From Selected Municipal Wells	18

LIST OF FIGURES

Number	Title	Following Page
1	Geologic Map Showing Location of Oil and Gas Fields, Middle Basin	2
2	Geologic Map Showing Location of Oil and Gas Fields, Lower Basin	2
3	Average Gain in South Platte River Flow from Ground-Water Return Flow Between Denver and Julesburg, Colorado, 1952-1961, Inclusive	6
4	Location of Selected Water Wells Tapping the Valley-Fill Aquifers, Middle Basin	8
5	Location of Selected Water Wells Tapping the Valley-Fill Aquifers, Lower Basin	8
6	Total Dissolved Solids, Chloride, and Sulfate Concentrations in Water from Wells Tapping the Valley-Fill Aquifers, Middle Basin	9
7	Total Dissolved Solids, Chloride, and Sulfate Concentrations in Water from Wells Tapping the Valley-Fill Aquifers, Lower Basin	9
8	ABS Concentrations in Water from Wells Tapping the Valley-Fill Aquifers, Middle Basin	17
9	ABS Concentrations in Water from Wells Tapping the Valley-Fill Aquifers, Lower Basin	17

LIST OF FIGURES
(Continued)

Number	Title	Following Page
10	Nitrate Concentrations in Water from Wells Tapping the Valley-Fill Aquifers, Middle Basin	17
11	Nitrate Concentrations in Water from Wells Tapping the Valley-Fill Aquifers, Lower Basin	17

ACKNOWLEDGMENTS

The assistance and cooperation of many State, local, and Federal agencies are gratefully acknowledged by the Federal Water Pollution Control Administration. Particular appreciation is expressed to the following for data and advice furnished by their staff members:

Colorado Water Pollution Control Commission
Denver, Colorado

Colorado State Department of Public Health
Engineering and Sanitation Division
Denver, Colorado

Colorado Water Conservation Board
Denver, Colorado

State Engineer of Colorado
Ground-Water Section
Denver, Colorado

Colorado Oil and Gas Conservation Commission
Denver, Colorado

Colorado State University
Engineering Research Center
Fort Collins, Colorado

Boulder County Health Department
Boulder, Colorado

Northeast Colorado Health Department
Sterling, Colorado

Weld County Health Department
Greeley, Colorado

U. S. Bureau of Reclamation, Region 7
Denver Development Office
Denver, Colorado

U. S. Geological Survey
Water Resources Division
Denver, Colorado

U. S. Department of Agriculture
Soil Conservation Service
Denver, Colorado

SUMMARY AND CONCLUSIONS

Ground-water supplies in the middle and lower South Platte River Basin are obtained principally from the valley-fill aquifers, the Tertiary aquifers, the artesian bedrock aquifers of Cretaceous age, and the fractured Precambrian crystalline rocks. The water-bearing characteristics of the valley-fill aquifers are very favorable for developing large low-cost water supplies from shallow wells for irrigation and large-scale municipal and industrial uses. These wells are located throughout most of the main South Platte River valley and in parts of its tributary valleys where sufficient thicknesses of saturated deposits occur. The artesian bedrock aquifers, aquifers in the rocks of Tertiary age, and the fractured crystalline rocks generally are not capable of yielding large quantities of ground water. However, these aquifers are important sources of water to several thousand wells which supply water for residential, stock, small industrial, and small municipal uses.

Over 9600 water wells withdraw water from the aquifers in the middle and lower Basin. Total withdrawals of ground water are estimated at about 1.22 million acre-feet per year. Agricultural irrigation is the largest user of ground water; withdrawals were about 1.17 million acre-feet in 1966 and comprised 96 percent of the total ground-water pumpage in the area. Twenty-seven municipal water systems supplied about 19,200 acre-feet of ground water to a population of 37,300 in 1965.

The chief source of recharge to the valley-fill aquifers in the main valley and most of its tributary valleys in the middle South Platte River Basin is from river water delivered to the irrigated lands and resulting seepage from farms, canals, and reservoirs. At least 50 percent of the South Platte River water diverted for irrigation enters the valley-fill aquifers. Most of this seepage moves downgradient through the valley-fill aquifers, subsequently returning to the South Platte River. Over a period of years, pumpage from wells in the valley-fill aquifers in most agricultural areas is balanced by recharge.

All unconfined water-bearing formations in the area are susceptible to pollution from surface or near-surface waste sources. Over 149 oil and gas fields produce saline waste waters which are temporarily held or stored in unlined pits. Seepage from these pits is adversely affecting the quality of water in unconfined aquifers. The surface casing depths of petroleum wells are largely inadequate insofar as providing optimum protection of all fresh-water formations penetrated by these deep boreholes.

Widespread pollution by alkyl benzene sulfonate (ABS) exists in the valley-fill aquifers in the upper part of main South Platte River valley and its southern tributary valleys in southwestern Weld County. The principal source of ABS in the aquifers was sewage-laden recharge from the South Platte River. The affected areas receive a major part of the sewage treatment plant effluents originating in the Denver

Metropolitan area. Septic tanks have contributed significant amounts of ABS to the unconfined aquifers. Although the manufacture of ABS was discontinued in June 1965, much of the ABS in the shallow aquifers will persist for several decades in the future. Thirteen municipal water systems distribute well water containing appreciable amounts of ABS.

The principal source of nitrate in the valley-fill aquifers is fertilizers applied to the irrigated croplands. Sewage plant effluents from the Denver Metropolitan area have also contributed significant amounts of nitrate to the shallow aquifers in the irrigated areas of southwestern Weld County. Feedlot wastes probably contribute large amounts of nitrate to the unconfined aquifers in localized areas. Nitrate (NO_3) concentrations in the valley-fill aquifers generally exceed 20 milligrams per liter (mg/l) and are greater than 45 mg/l in many cases. The municipal water systems of Fort Lupton, LaSalle, Gilcrest, and Nunn supply well waters containing nitrate in excess of 45 mg/l, the upper limit of the U. S. Public Health Drinking Water Standards. These waters are potentially dangerous when used for infant feeding. Undoubtedly, a large number of domestic wells also provide water with nitrate in excess of this upper limit.

RECOMMENDATIONS

In view of the susceptibility of unconfined aquifers to contamination and pollution, the Colorado Water Pollution Control Commission should consider the following measures:

1) Elimination of septic tanks in densely-populated areas.

2) Routine monitoring for changes in chemical quality of municipal water supply wells tapping the unconfined aquifers.

3) Impermeable lining of ponds, ditches, and other means of disposing of industrial and agricultural wastes in areas where pollution may cause real or potential interference to water uses.

With particular reference to saline contamination from petroleum field operations, additional measures are given as follows:

4) Frequent inspection and approval of waste disposal procedures, including pond lining and completion of salt-water injection wells.

5) Proper methods of plugging abandoned and exploratory wells, and establishing minimum depths for surface casings.

With particular reference to nitrate contamination, it is suggested that:

6) Water supply wells be inventoried and routinely sampled with respect to existing water quality, and municipalities having excess nitrate content be advised concerning hazards of using present supplies.

INTRODUCTION

The investigation of ground-water conditions in the middle and lower South Platte River Basin was undertaken as an integral part of the water pollution study currently being conducted by the South Platte River Basin Project. Ground water is used extensively throughout the area for public, domestic, industrial, and irrigation supplies.

The main purposes of the ground-water study were to assess sources and extent of pollution of the water-bearing formations and provide information to the other activities of the Project in overall evaluation of the stream pollution problems in the Basin.

This study is based on published and unpublished information received from many Federal, State, and local agencies, together with various field investigations conducted by the Project. Officials of municipal water systems furnished information about their water systems, and assisted in collection of samples and measurements.

Locations of wells, sampling points, and some other features in this report are described by using a numbering system based on the U. S. Bureau of Land Management's system of land subdivision. The numbering system is explained in Appendix A.

AREA OF INVESTIGATION

The study area lies in the South Platte River Basin of northeastern Colorado as shown on the index map of Figure 1. The middle and lower Basin in Colorado covers approximately 9700 square miles and includes all or parts of Boulder, Larimer, Weld, Morgan, Washington, Logan, and Sedgwick Counties. The population of the area was estimated at 275,650 on January 1, 1964 (1). Approximately 781,000 acres of farm land are presently irrigated. The principal crops are alfalfa, small grains, corn, and sugar beets. Industries in the area include sugar beet processing mills, feedlots, meat packing plants, canneries, and oil and gas fields.

Most of the study area lies in the Colorado Piedmont section of the Great Plains physiographic province. A narrow band across the northern edge and eastern end of the study area is in the High Plains section of the Great Plains province. The extreme western part of the area, west of the cities of Boulder and Fort Collins, lies on the east flank of the Front Range mountains of the Southern Rocky Mountain physiographic province. The altitude of the land surface in the main valley of the South Platte River is about 3460 feet above sea level at the east end of the Basin near the Town of Julesburg; 4527 feet at Hardin, and 4900 feet at the southwest end of the study area near Fort Lupton. The Front Range part of this area lies at altitudes generally between 6500 and 11,000 feet.

The principal western tributaries of the South Platte River are perennial streams and include the St. Vrain, Big Thompson, and Cache la Poudre Rivers. The northern tributary streams have intermittent flows and include Crow, Pawnee, Cedar, and Lodgepole Creeks. The southern tributary streams are intermittent and include Box Elder, Lost, Kiowa, Bijou, Beaver, and Badger Creeks.

GEOLOGY AND OCCURRENCE OF GROUND WATER

Most of the study area lies in the Denver-Julesburg basin: a large, asymmetrical structural basin that occurs east of the Front Range mountains in northeastern Colorado and adjacent parts of southeastern Wyoming and western Nebraska. The principal aquifers in the area occur in four general groups of rocks: the crystalline rocks of Precambrian age; the sedimentary bedrock formations, largely Cretaceous in age; the unconsolidated and consolidated sedimentary beds of Tertiary age; and the unconsolidated valley-fill deposits of Quaternary age. The surface distribution of these rock units is shown on Figures 1 and 2.

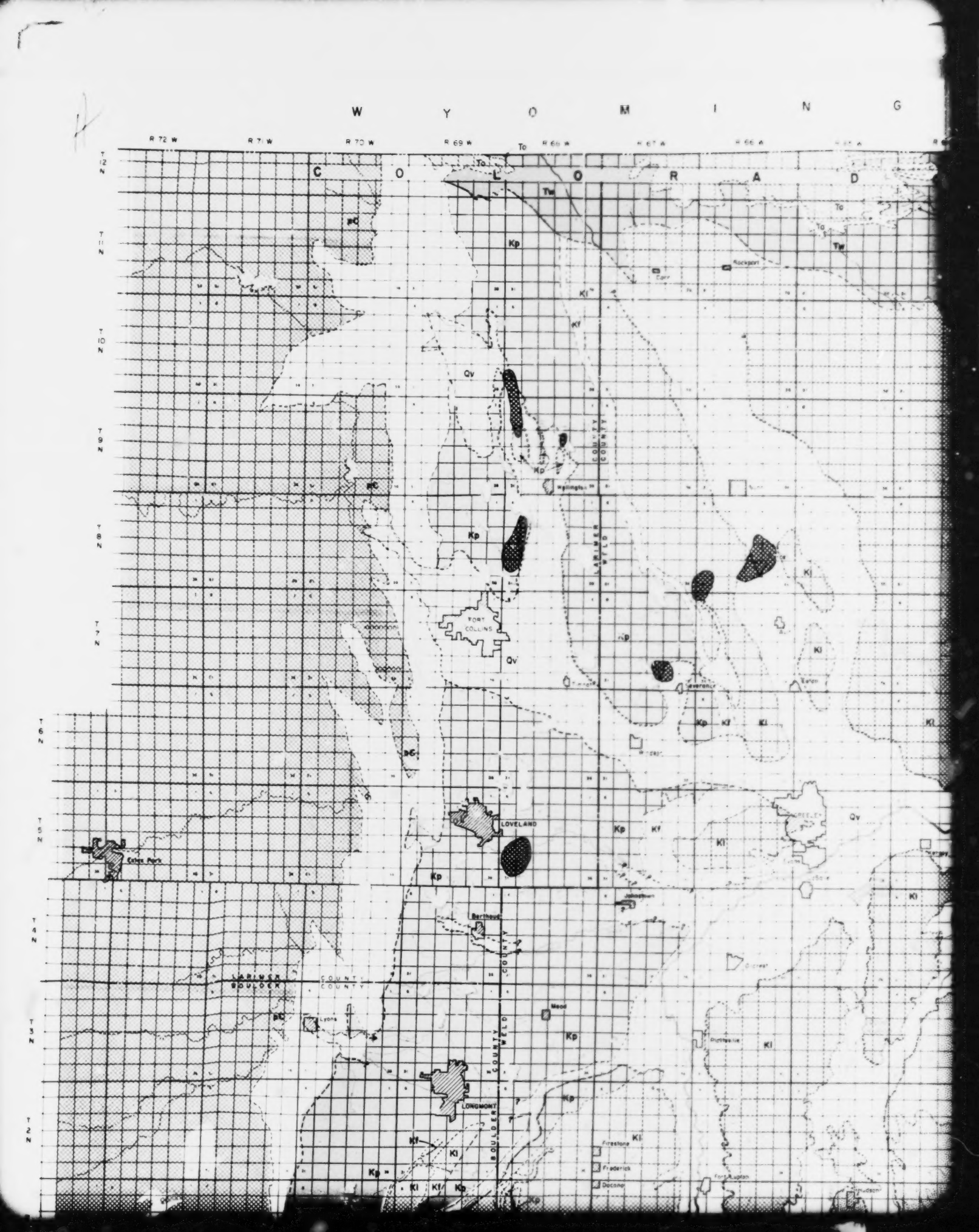
Crystalline Rock Aquifers

The crystalline rocks of Precambrian age are exposed in the Front Range mountains in the western parts of Boulder and Larimer Counties. Ground water generally occurs under unconfined conditions in the fractured and weathered zones of these dense igneous rocks. Although water wells tapping the crystalline rocks generally yield small quantities of water (5 to 10 gallons per minute), this aquifer is often the only source of water to residences, recreational facilities, motels, and restaurants in the mountain areas.

Artesian Aquifers

The principal artesian aquifers in the area occur in the sedimentary bedrock formations of Cretaceous age and consist of the Pierre Shale, Fox Hills Sandstone, and Laramie Formation. These formations are exposed at the surface throughout much of the study area east of the Front Range mountains and foothills. From their outcrops they dip inward toward the north-south axis of the trough which forms the deepest part of the Denver-Julesburg structural basin. In the study area, the axis of this structural trough extends from the southern boundary of Weld County in T1N, R67W northward through Greeley and thence northward to the State line in T12N, R66W (2). Except in their outcrop areas, the water-bearing beds of these formations contain water under artesian pressure.

The Pierre Shale formation consists mainly of a massive sequence of relatively impermeable shale, silt, and sandy shale, and contains thin lenses of sandstone. The thickness of this formation is estimated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Carr
Wellington
FORT COLLINS
Loveland
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Mead
Firestone
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Dacono
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Greeley
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Lyons
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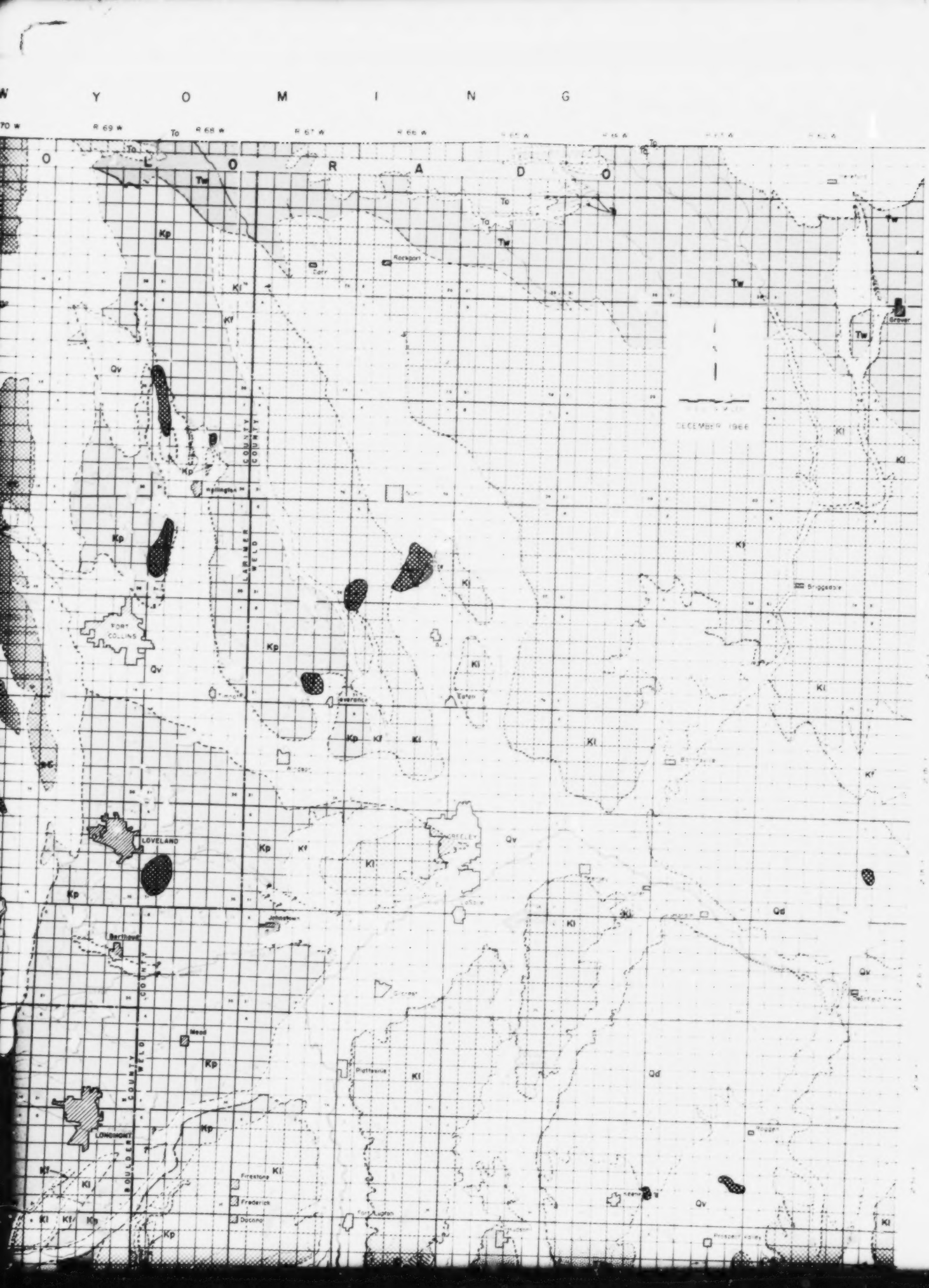
WELD COUNTY
BOULDER COUNTY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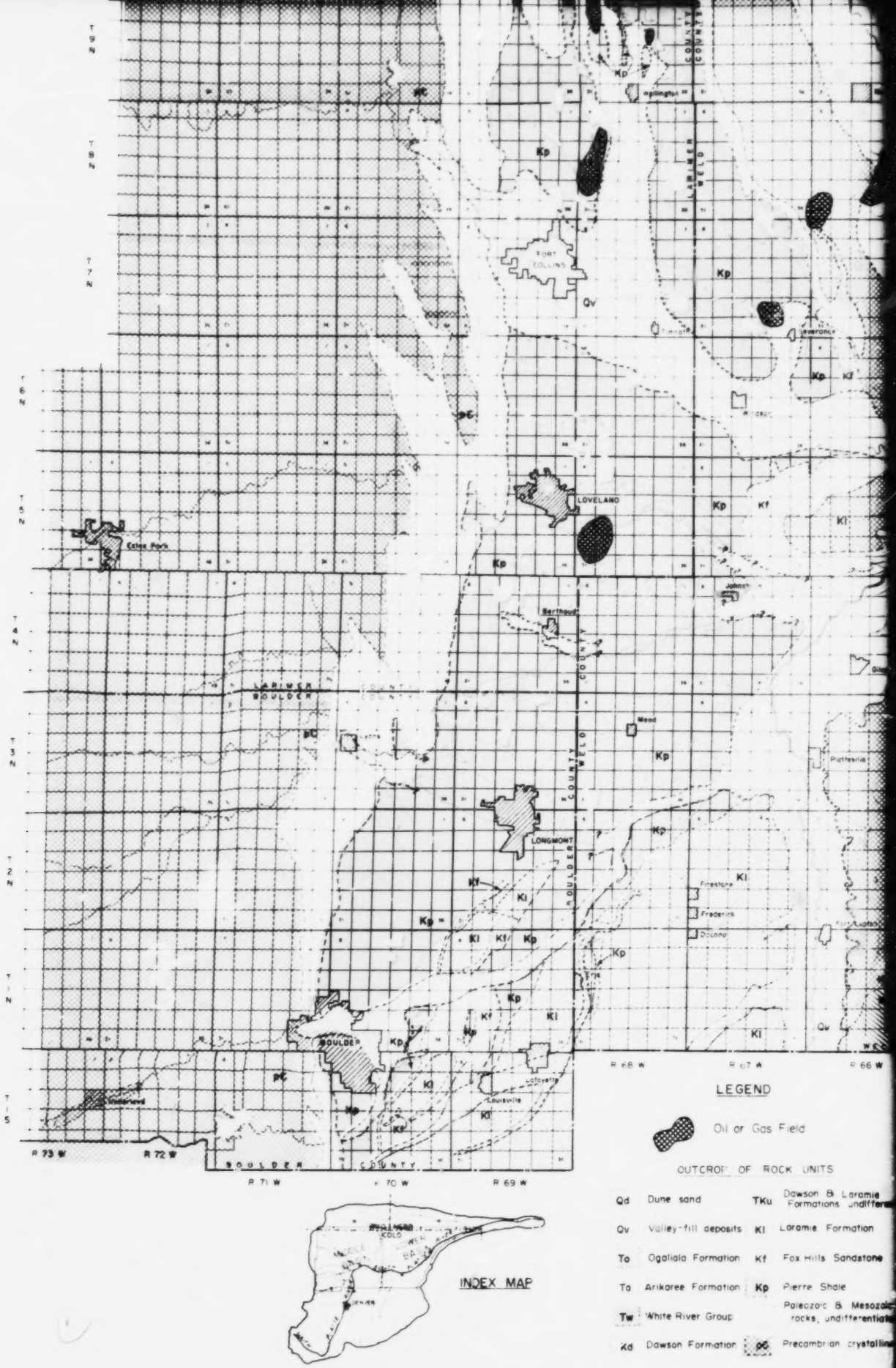
Brigadier
Eaton
Lawrence
Greeley
LOVELAND
Johnstown
Berthoud
Mead
Platteville
Longmont
Firestone
Frederick
Dacono
Fort Lupton
LARIMER COUNTY
WELD COUNTY
BOULDER COUNTY
DECEMBER 1966


LOVELAND
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Superior
Louisville
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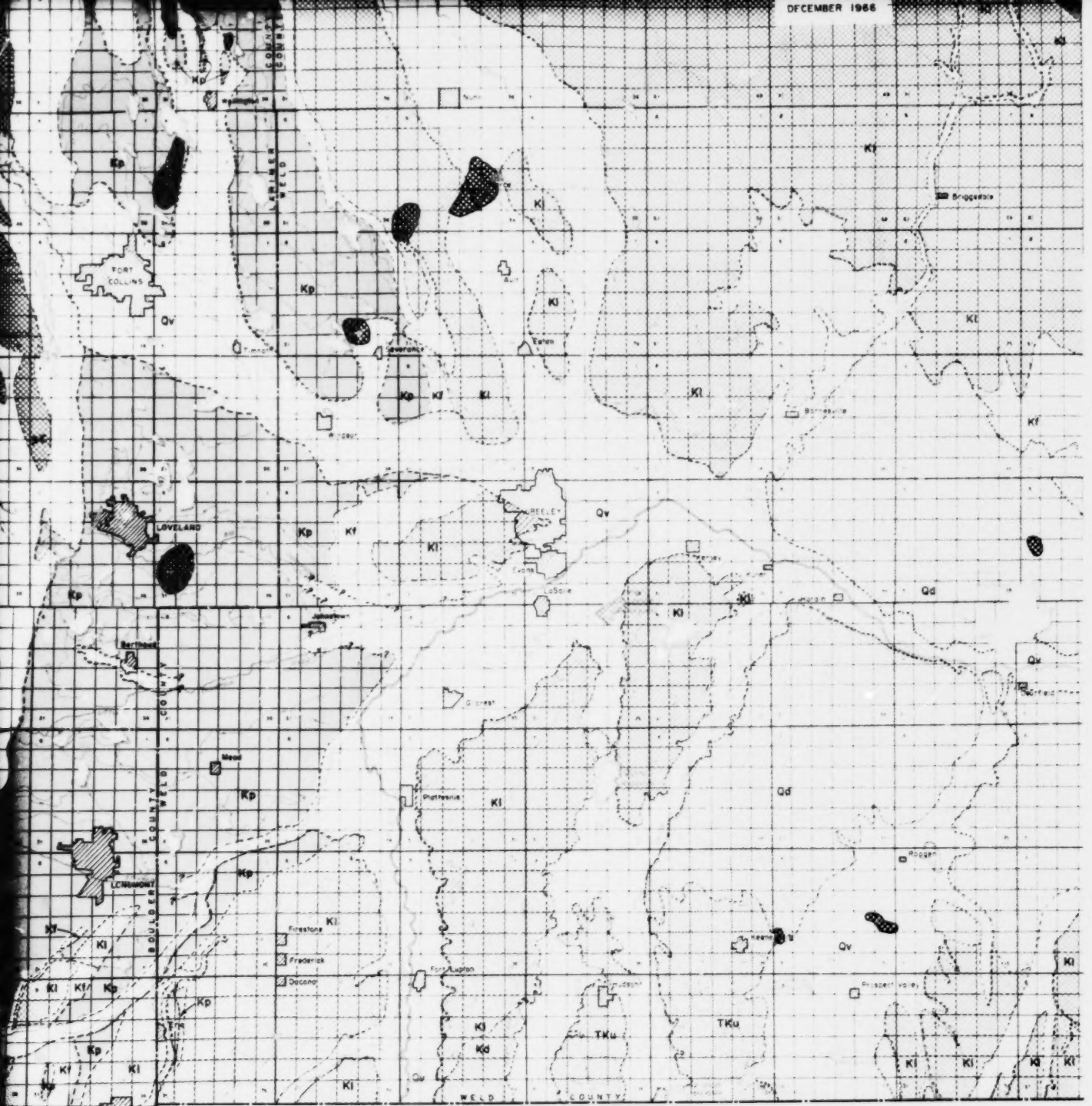
LARIMER COUNTY
WELD COUNTY
BOULDER COUNTY
LEGEND
Oil or Gas Field
OUTCROP OF ROCK UNITS
Qd Dune sand
Qv Valley-fill deposits
To Ogallala Formation
Ta Arikaree Formation
Tw White River Group
Kd Dawson Formation
TKu Dawson & Laramie Formations undifferentiated
Kl Laramie Formation
Kf Fox Hills Sandstone
Kp Pierre Shale
Paleozoic & Mesozoic rocks, undifferentiated
pC Precambrian crystalline
INDEX MAP

DECEMBER 1966



LEGEND

Oil or Gas Field

OUTCROP OF ROCK UNITS

Qd	Dune sand	TKu	Dawson & Laramie Formations undifferentiated
Qv	Valley-fill deposits	Kl	Laramie Formation
To	Ogallala Formation	Kf	Fox Hills Sandstone
Ta	Arikaree Formation	Kp	Pierre Shale
Tw	White River Group		Paleozoic & Mesozoic rocks, undifferentiated
Kd	Dawson Formation		Precambrian crystalline rocks

INDEX MAP

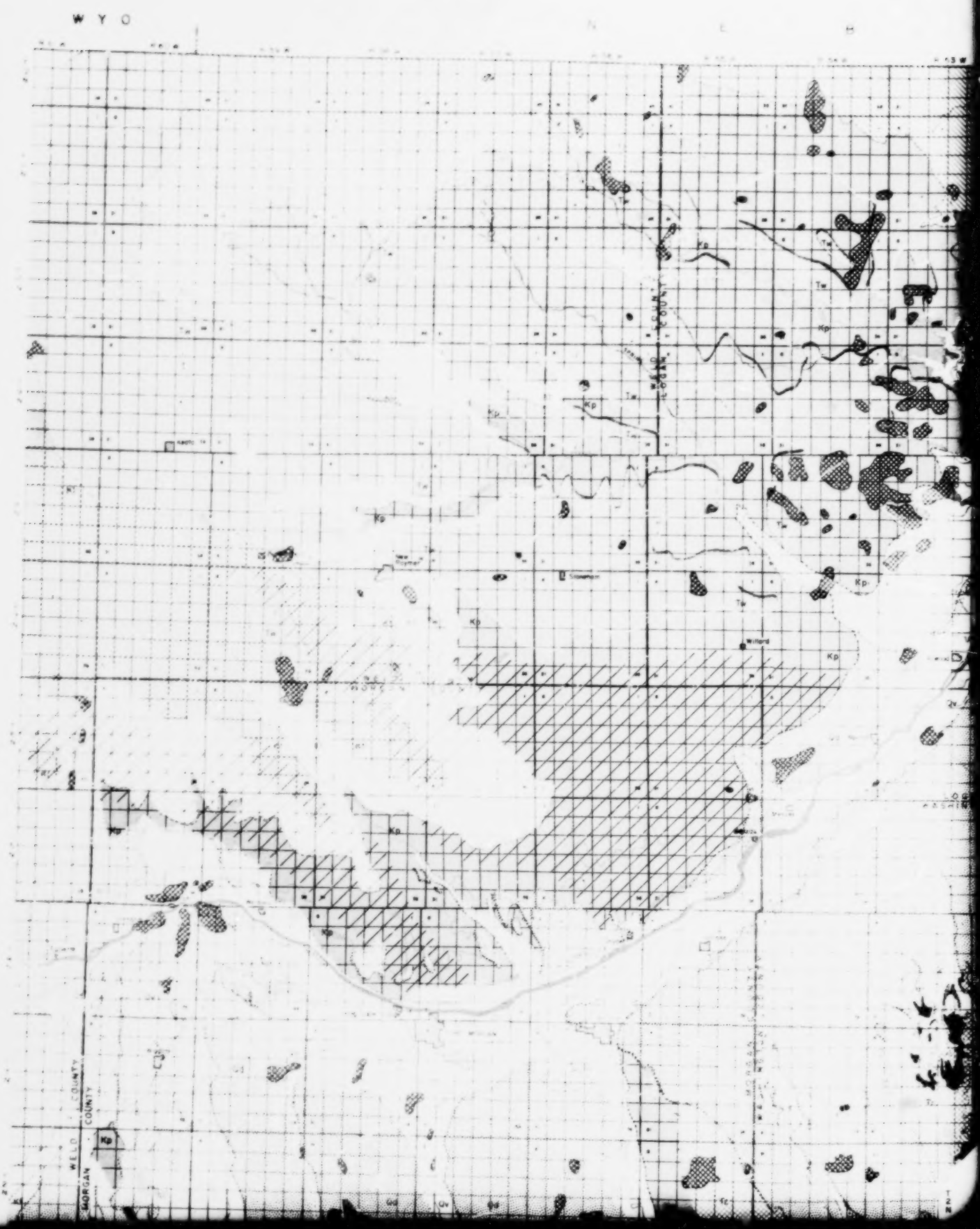
SOUTH PLATTE RIVER BASIN PROJECT

GEOLOGIC MAP SHOWING LOCATION OF OIL & GAS FIELDS MIDDLE BASIN

U S DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration

FIGURE 1

3-a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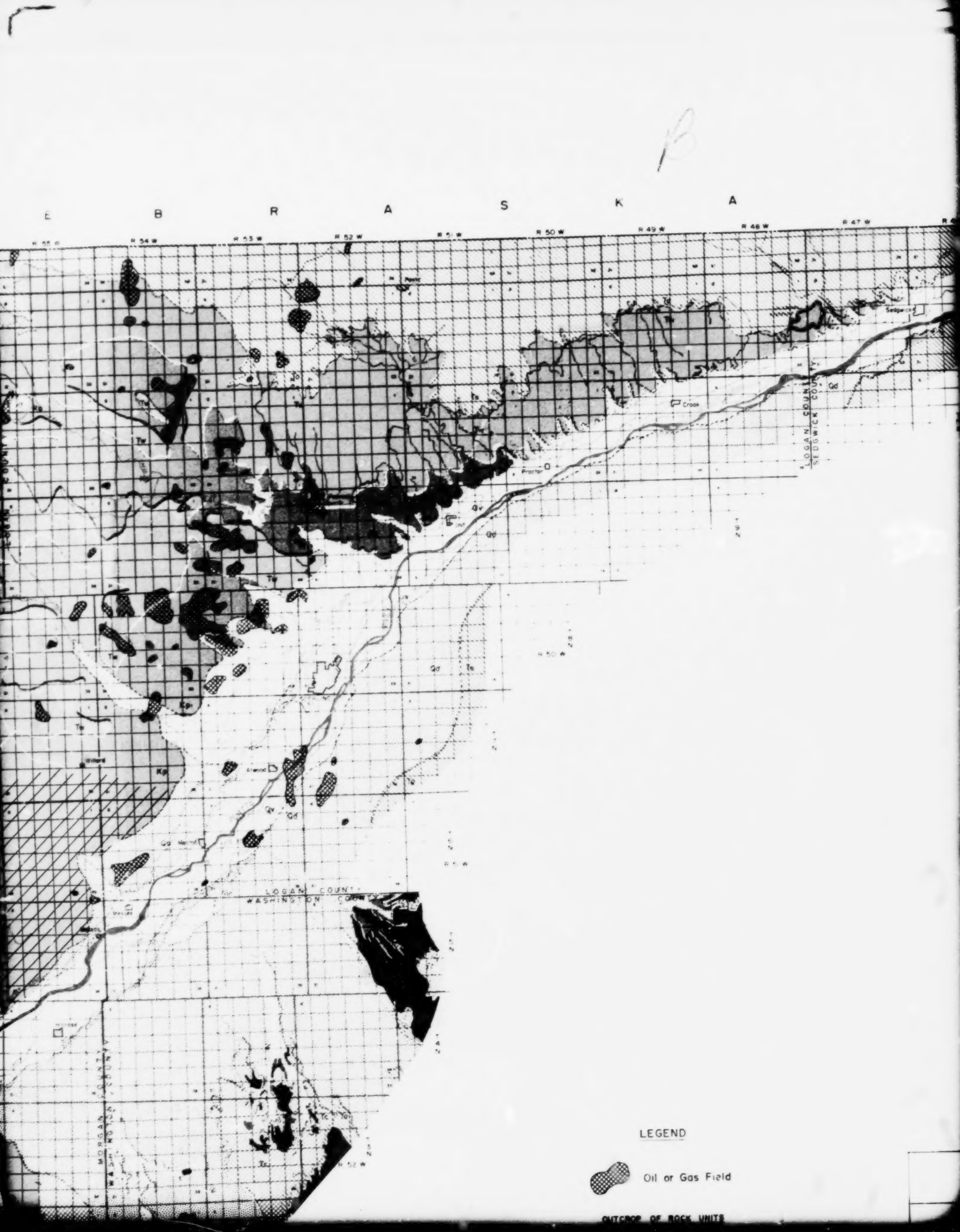
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LOGAN COUNTY
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WASHINGTON COUNTY
LEGEND
Oil or Gas Field
OUTCROP OF ROCK UNITS

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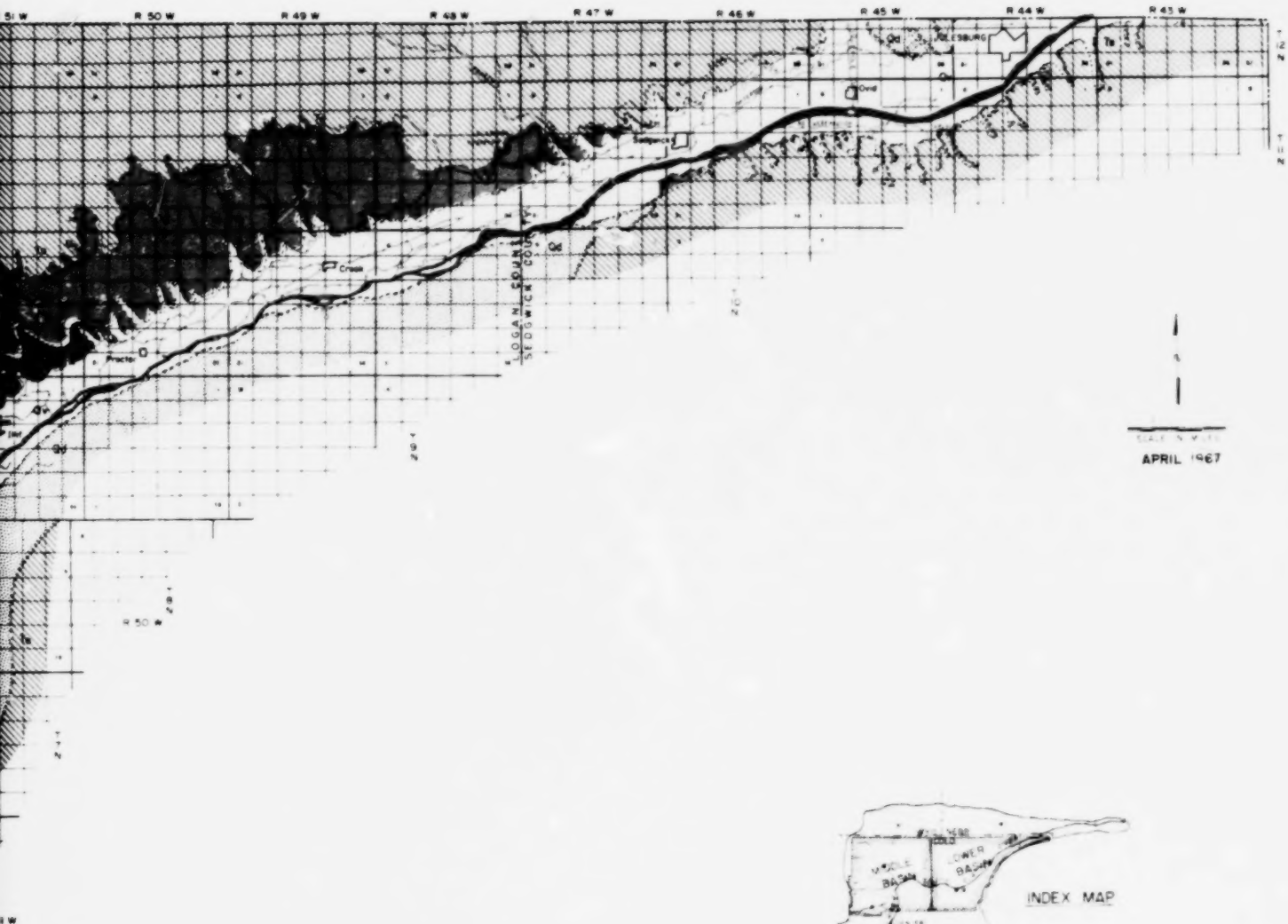


INDEX MAP

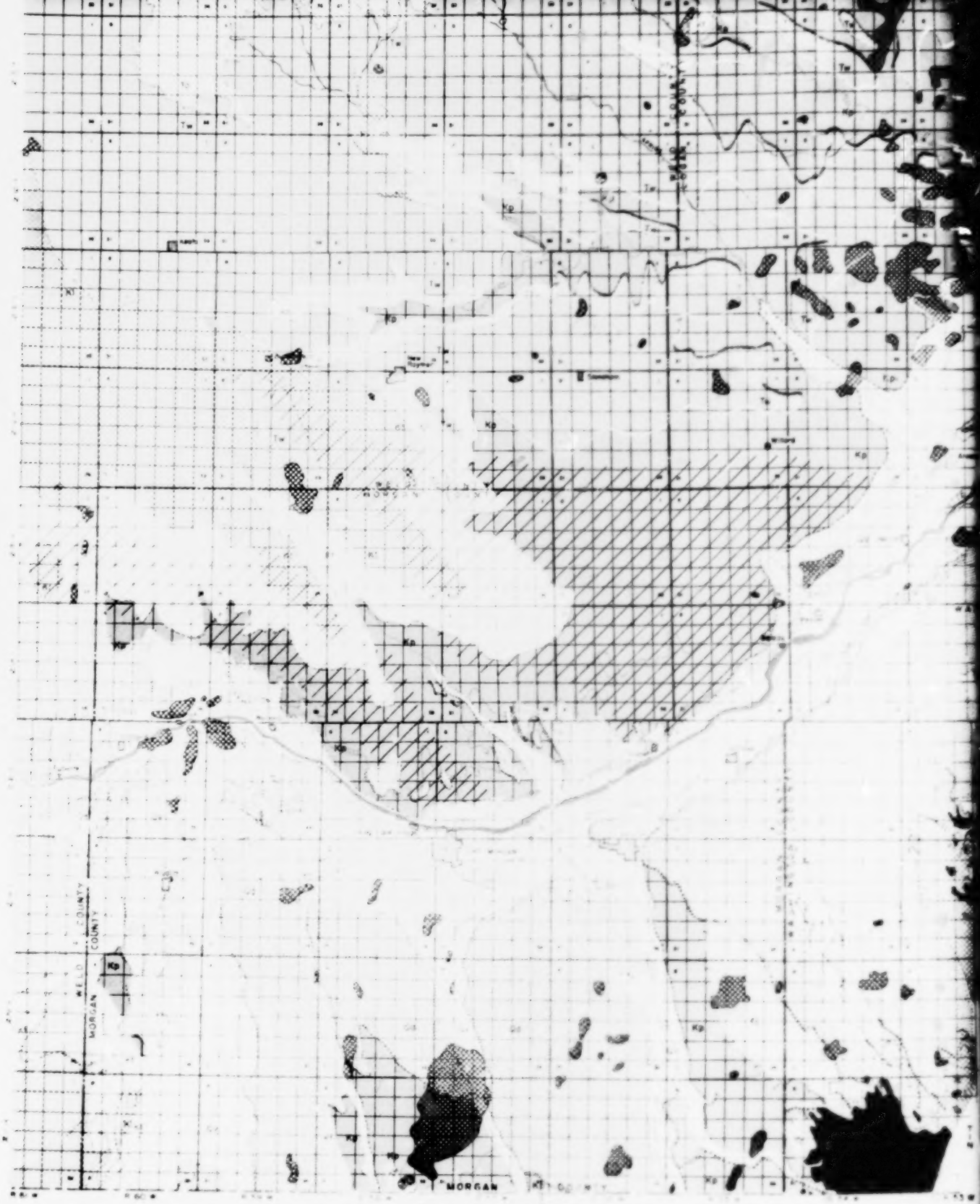
LEGEND

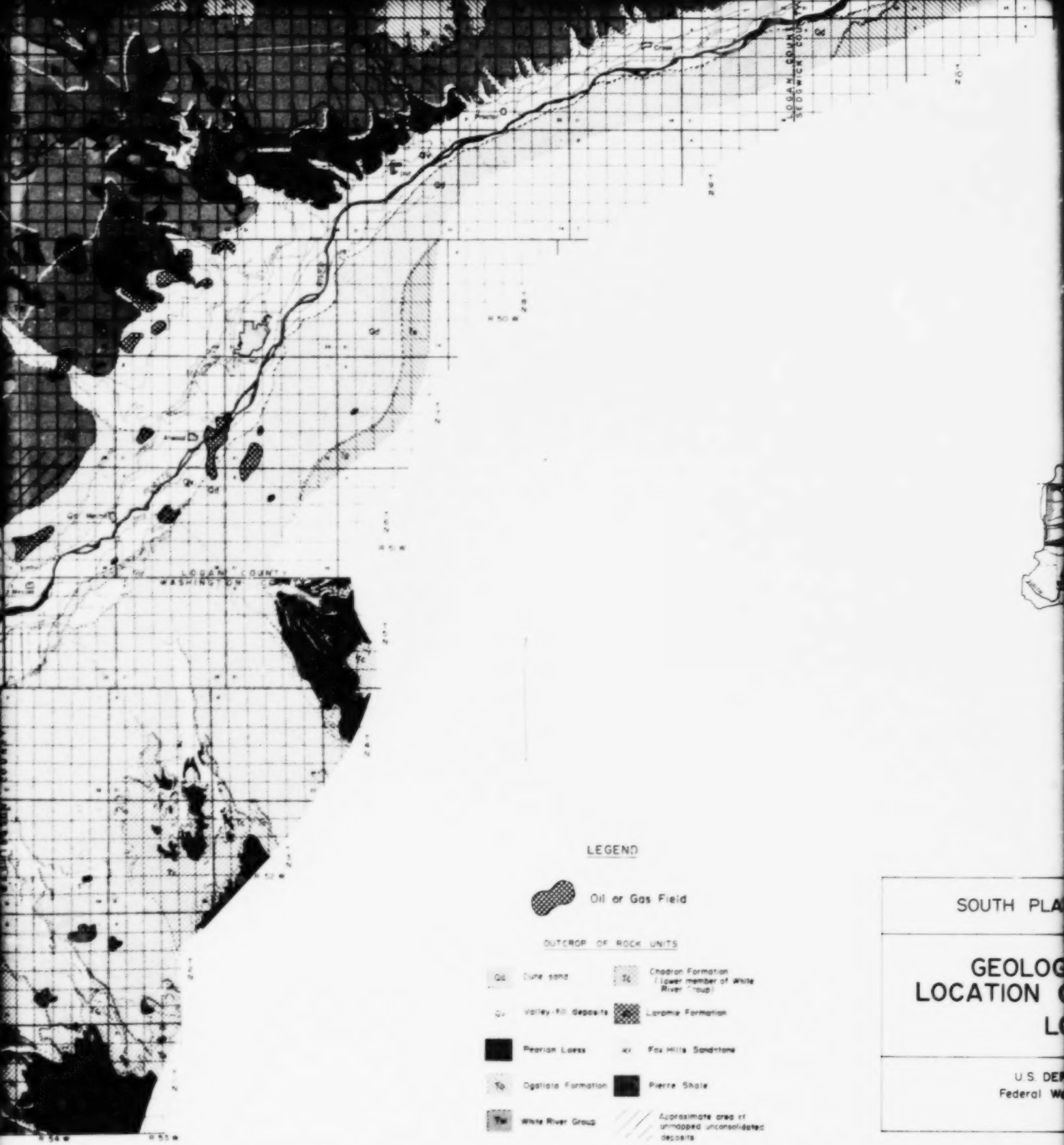
Oil or Gas Field

OUTCROP OF ROCK UNITS

SOUTH PLATTE RIVER BASIN PROJECT

GEOLOGIC MAP SHOWING


MORGAN COUNTY
MORGAN



LEGEND

Oil or Gas Field

OUTCROP OF ROCK UNITS

- Qd — Dune sand
- Qv — Valley-fill deposits
- Peorian Loess
- Tp — Ogallala Formation
- Tw — White River Group
- Tc — Chadron Formation (lower member of White River Group)
- Kl — Laramie Formation
- Kf — Fox Hills Sandstone
- Pierre Shale
- Approximate area of unmapped unconsolidated deposits

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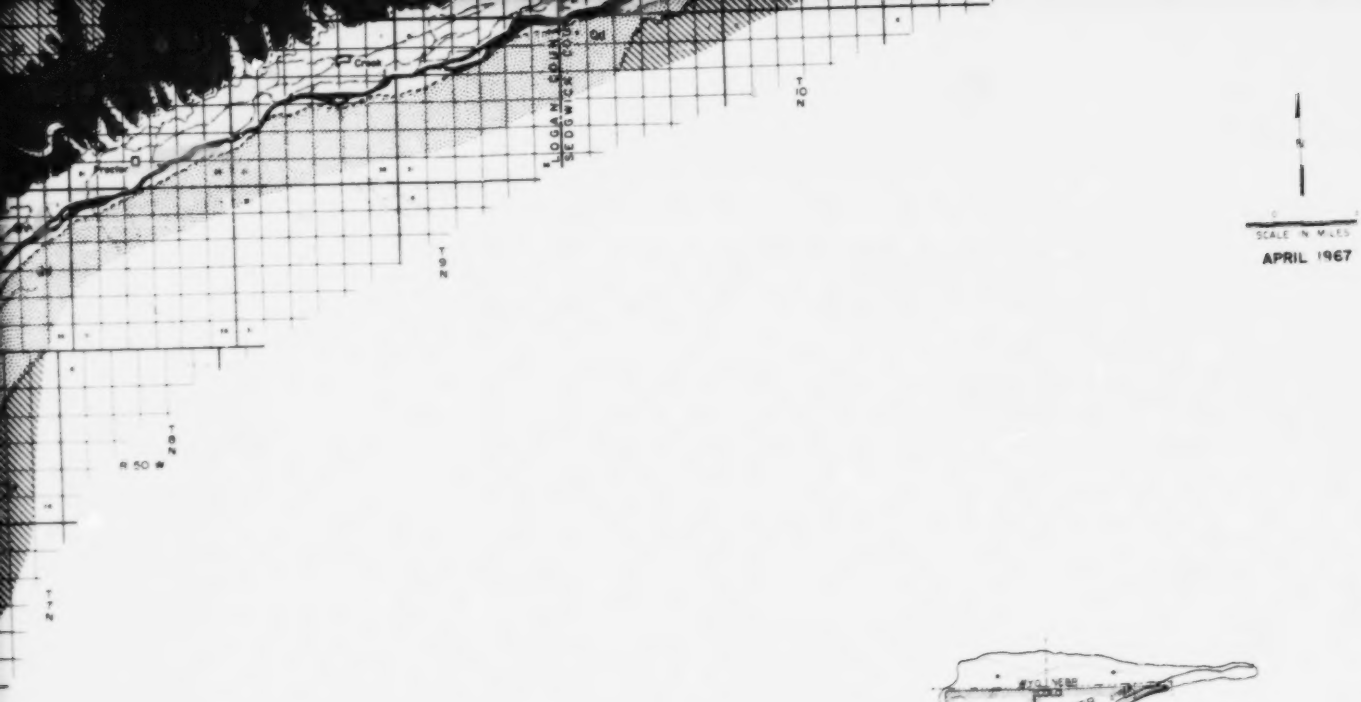
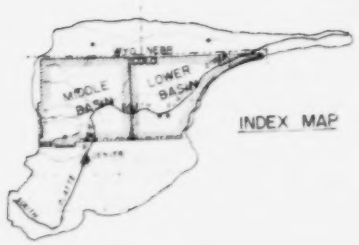




INDEX MAP

LEGEND

Oil or Gas Field

OUTCROP OF ROCK UNITS

- Qd — Dune sand
- Qv — Valley-fill deposits
- Peoria Loess
- Og — Ogallala Formation
- Tw — White River Group
- Tc — Chadron Formation (lower member of White River Group)
- Laramie Formation
- Kf — Fox Hills Sandstone
- Pierre Shale
- Approximate area of unmapped unconsolidated deposits

SOUTH PLATTE RIVER BASIN PROJECT

GEOLOGIC MAP SHOWING LOCATION OF OIL & GAS FIELDS LOWER BASIN

U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration

Denver, Colorado

FIGURE 2

E

3-f

F

to be as great as 7000 feet in central Weld County. Although many small capacity wells tap the sandstone lenses of the Pierre, it is considered a poor source of water because of the erratic occurrence of its thin water-bearing zones.

The Fox Hills Sandstone overlies the Pierre Shale and consists chiefly of moderately cemented sandstone interbedded with silty shale and silty sandstone. The formation crops out in eastern Larimer and Boulder Counties, and in the uplands that border the main South Platte River valley and its tributary valleys in central Weld, Morgan, and Logan Counties. The thickness of the Fox Hills ranges up to 400 feet in the area. The formation generally yields small quantities of water (5-30 gpm) to wells used to supply livestock, residences, and small municipal systems.

The Laramie Formation overlies the Fox Hills Sandstone formation and crops out east of the Front Range throughout much of the middle Basin and the western part of the lower Basin. The formation consists chiefly of soft shale and clay interbedded with layers of sand and often contains evaporite materials. The thickness of this formation ranges up to about 600 feet in the western part of Weld County. Water wells tapping the water-bearing zones of the Laramie generally yield small amounts of water (5-10 gpm), but in a few instances reportedly yield 50 to 300 gpm. Numerous wells supply water for livestock, residential, small industrial, and small municipal uses. The chemical quality of water from individual water-bearing zones differs widely from each other. High sulfate water is commonly produced from wells located north of the South Platte River in Weld County and in the lower Cache la Poudre Basin of eastern Larimer County.

The artesian aquifers of the sedimentary bedrock formations occurring in the middle and lower Basin are not prolific sources of water. However, several thousand water wells tapping these aquifers are important sources of supply for individual residences, livestock, small industries, and small municipal water systems. Detailed studies are needed to determine the depth, areal extent, chemical quality, and hydraulic characteristics of the water-bearing zones in the Cretaceous formations in order to fully utilize these aquifers as sources of water.

Tertiary Aquifers

The White River Group and Ogallala Formation of Tertiary age crop out from the Front Range eastward in the northern and eastern parts of the Basin. Ground water in these formations is generally unconfined. The White River Group consists chiefly of massive siltstone. Recent studies by the U. S. Geological Survey (3) indicate this formation is not a prolific aquifer in northeastern Colorado. Many of the large capacity wells reported to tap the White River rocks probably yield water from younger stream deposits of sand and gravel. Most of the wells tapping the permeable zones of the White River Group in northeastern Colorado yield relatively small quantities of water for livestock, residential, and small municipal uses.

The Ogallala Formation crops out along the north edge and east end of the area in the High Plains section of the Basin. The Ogallala consists mainly of beds of clay, silt, sand, gravel, and caliche, and contains cemented ledges of sand and gravel. Owing to its relatively thin saturated chickness, wells tapping the Ogallala Formation generally yield small to moderate quantities of good quality water (5-50 gpm) for livestock, domestic, and small municipal uses.

Valley-Fill Aquifers

In this report, the valley-fill deposits also include those unconsolidated surficial deposits described in the literature as alluvium, terrace deposits, and slope wash deposits. The valley-fill deposits, chiefly Quaternary in age, consist of sand, gravel, some cobbles, and thin beds of silt and clay. The surface distribution of the valley-fill deposits in the middle and lower Basin is shown in Figures 1 and 2 respectively. The greatest thicknesses of valley-fill materials occur in the main valley of the South Platte River and in the lower reaches of most of its western, northern, and southern tributary valleys. Studies conducted by the U. S. Geological Survey have delineated the valley-fill deposits in much of the study area.

In the main valley between the southern Weld County line and the town of Kuner, thicknesses of the saturated valley-fill deposits generally exceed 40 feet and are as much as 120 feet in certain areas (4). Saturated thicknesses of the valley-fill in the main valley downstream from the town of Orchard to the State line generally exceed 80 feet; saturated thicknesses range from about 160 to 240 feet throughout much of the main valley in the lower Basin (5). Depths to the water table in the main valley are generally less than 10 feet in the lowlands and extend to about 50 feet below the land surface in the upland areas.

The valley-fill deposits in the lower Cache la Poudre River Valley between Fort Collins and Greeley range up to about 100 feet in thickness (6). The fill ranges up to 100 feet in Boxelder Creek valley south of the Town of Wellington in eastern Larimer County, and averages about 40 feet in the tributary valleys of Lone Tree and Spring Creeks north of Greeley (6). In the upper valley of Crow Creek near the town of Hereford, several wells penetrate as much as 100 feet of terrace deposits (7).

The principal southern tributary valleys of the South Platte River in Weld and Morgan Counties contain extensive and thick deposits of valley-fill material. In the valleys of Box Elder Creek and Beebe Seep, saturated thicknesses generally exceed 40 feet and range up to about 100 feet near Milton Reservoir (4). In the valley of Lost Creek, the fill is estimated to range up to 140 feet in thickness north of the town of Roggen. Up to about 120 feet of fill occurs in the lower parts of Bijou Creek and Kiowa Creek valleys. In the lower ends of Badger and Beaver Creek valleys, saturated thicknesses range up to 120 and 100 feet respectively (5).

The valley-fill aquifers are the principal sources of the largest supplies of ground water in northeastern Colorado. Geologic conditions and water-bearing characteristics of these deposits are very favorable for developing low-cost water supplies from wells for large-scale uses. Large capacity wells produce up to 3000 gpm and yields of 500 gpm are common. Substantial quantities of ground water are in transient storage in the valley-fill deposits. During the period of 1950-1957, the U. S. Geological Survey (4)(5) estimated there was about 7.7 million acre-feet of recoverable water in most of the main valley of the South Platte River. Five million acre-feet of recoverable water were estimated to be in storage in the southern tributary valleys of Beebe Draw, Box Elder Creek, Lost Creek, Bijou Creek, Kiowa Creek, and Beaver Creek during this same period. Pumping tests of water wells conducted chiefly by the U. S. Geological Survey (8) revealed that the valley-fill aquifers are capable of transmitting large quantities of water. Results of these aquifer tests are summarized in the following tabulation:

Area	Number of Wells Tested	Range of Values of Coefficient of Permeability (gpd per sq ft)	Range of Values of Coefficient of Transmissibility (gpd per ft)
South Platte River Valley, Middle Basin	25	1,050-11,800	40,000-500,000
South Platte River Valley, Lower Basin	9	3,400- 7,000	95,000-750,000
Cache la Poudre River Valley	10	2,500-16,000	45,000-180,000
Boxelder Creek Valley, Larimer County	8	1,200- 8,900	50,000-320,000
Lone Tree Creek Valley	8	2,100-10,300	30,000-370,000
Spring Creek Valley	4	700-10,000	25,000-115,000
Lower Crow Creek Valley	1	2,900	60,000
Boulder Creek Valley	1	240	5,800
Beebe Draw	3	10,000-23,200	410,000-790,000
Box Elder Creek Valley, Weld County	2	800- 2,300	24,000- 90,000
Prospect Valley	3	1,550- 2,500	90,000-230,000

Sources of recharge to the valley-fill aquifers include precipitation, ground-water inflow, and seepage from irrigation ditches, irrigated farms, and influent tributary streams.

The chief source of recharge to the valley-fill aquifers in the main South Platte River valley and most of the tributary valleys is seepage of surface water diverted for agricultural use. Large quantities of surface water enter the aquifer from seepage in irrigation canals, storage reservoirs, and farm application. Irrigation ditch companies, located in the main valley and southern tributary areas, estimate their conveyance losses to be from 33 to 60 percent, most due to seepage from

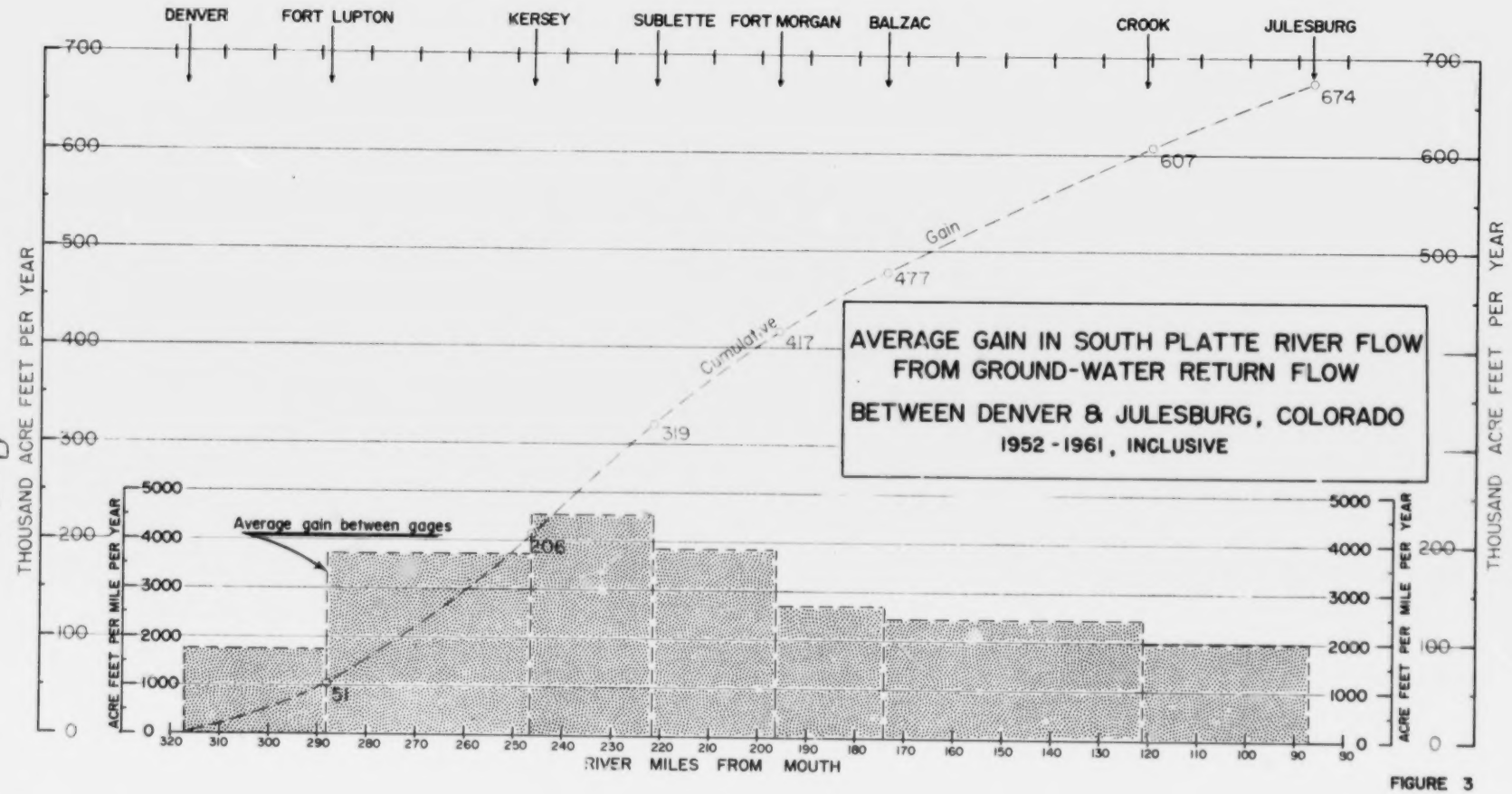
canals and storage reservoirs (4)(9)(10). Percolation on irrigated farms ranges from 25 to 40 percent (4)(9)(10) of the amount of water delivered to farms. Thus, of the 993,000 acre-feet of South Platte River water diverted annually (11) during the period 1952-1961, it is concluded that at least one-half of this amount, or about 497,000 acre-feet per year, entered the unconfined aquifers in the agricultural areas of the main valley and its southern tributary valleys. Precipitation accounts for a small part of the total recharge to the valley-fill deposits in areas that receive surface water. Less than 10 percent of 13.1 inches of annual precipitation enters the unconfined aquifers in areas covered by valley-fill and dune sand deposits.

The South Platte River is a gaining stream throughout most of its course where accretions in flow are caused by discharges of ground water from the valley-fill deposits. Studies (12) indicate a total annual gain in river flow of 674,000 acre-feet per year between the Denver and Julesburg gaging stations during the period of 1959-1961, or an overall average gain of about 2900 acre-feet per mile per year. As shown in Figure 3, the highest rates of ground-water return flow occur in the stretch of the River between Fort Lupton and Fort Morgan, where average annual gains range from 3700 to 4500 acre-feet per mile. The high rate of increase in this stretch of the River reflects greater amounts of recharge to the valley-fill aquifer in contiguous areas containing the highest density of canals, storage reservoirs, and irrigated lands in the main valley.

Water level measurements (4)(5)(6)(9)(13)(14)(15) do not show significant long-term declines in the heavily pumped areas of the main South Platte River valley and the lower Cache la Poudre valley, indicating that over a period of years discharges from the shallow aquifers in these valleys are balanced by recharge. Steady long-term declines in water levels are occurring in some southern tributary valleys. For example, in the Prospect Valley area of southeast Weld County, withdrawals from irrigation wells exceed recharge by about 10,500 acre-feet per year (10). Records of water wells located in the northern part of the Prospect Valley area show water levels have declined about one foot per year since withdrawals increased sharply in 1950 (10)(13)(14)(15). Similar declines in water levels have occurred in irrigated areas of Kiowa, Bijou, and Beaver Creeks since 1947 (5)(15).

Dune Sand Deposits

As shown on Figures 1 and 2, dune sand deposits blanket large areas in Weld, Morgan, Logan, and Washington Counties. Thickness of the dune sands ranges up to 100 feet in Morgan County (5). Although these deposits yield only small quantities of water to stock wells, the dune sand mantle serves as large infiltration areas for precipitation and storm runoff, recharging underlying or adjacent aquifers.


DENVER
FORT LUPTON
KERSEY
SUBLETTE
FORT MORGAN
BALZAC
CROOK
JULESBURG
700
600
500
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300
200
100
0
674
607
477
417
319
Gain
Cumulative
AVERAGE GAIN IN SOUTH PLATTE RIVER FLOW
FROM GROUND-WATER RETURN FLOW
BETWEEN DENVER & JULESBURG, COLORADO
1952 - 1961, INCLUSIVE
THOUSAND ACRE FEET PER YEAR
Average gain between gages
206
51
5000
4000
3000
2000
1000
0
ACRE FEET PER MILE PER YEAR
320 310 300 290 280 270 260 250 240 230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80
RIVER MILES FROM MOUTH

FIGURE 3

USE OF GROUND WATER

At least 9947 wells tap the water-bearing formations in the middle and lower South Platte River Basin. Table I shows the use and number of water wells in the area and is based primarily on the records of the State Engineer of Colorado (16) of water well registrations through June 1964.

The data shown in Table I indicate that 5843 water wells are used for irrigation and stock watering; over 3500 wells supply individual residences, motels, restaurants, and trailer parks; 96 wells supply municipal water systems, and 114 wells supply small to large quantities of water for industrial use. Most of the large capacity irrigation, industrial, and municipal wells, with yields in excess of 200 gpm, tap the valley-fill aquifers. Locations of most of these wells are shown in Figures 4 and 5 and are based on records of the U. S. Geological Survey (4)(5)(6)(17) and the State Engineer of Colorado (16).

Irrigation is the largest use of ground water in the area. Based on electrical consumption of pumping units (20), an estimated 1.17 million acre-feet of water were pumped from irrigation wells in 1966, nearly all of this amount from the valley-fill aquifers. Table II gives an inventory of municipal water systems compiled by the Project. The data shows that 96 water wells supplied an estimated 10,294 acre-feet of water to a population of 37,312 in 1965. It is estimated that domestic wells supply at least 2860 acre-feet of water. The actual amount of water withdrawn from domestic wells may be several times this amount, owing to the large number of unreported wells drilled in the main valley of the South Platte River and its western tributary valleys. Principal industrial users of ground water include sugar beet processing factories and water flood projects of oil fields. Five sugar beet factories pumped about 1920 acre-feet of well water during the 1963-64 processing season (18), and 21 water flood projects injected about 5570 acre-feet of well water in 1960 (19).

CHEMICAL QUALITY OF GROUND WATER

Valley-Fill Aquifers

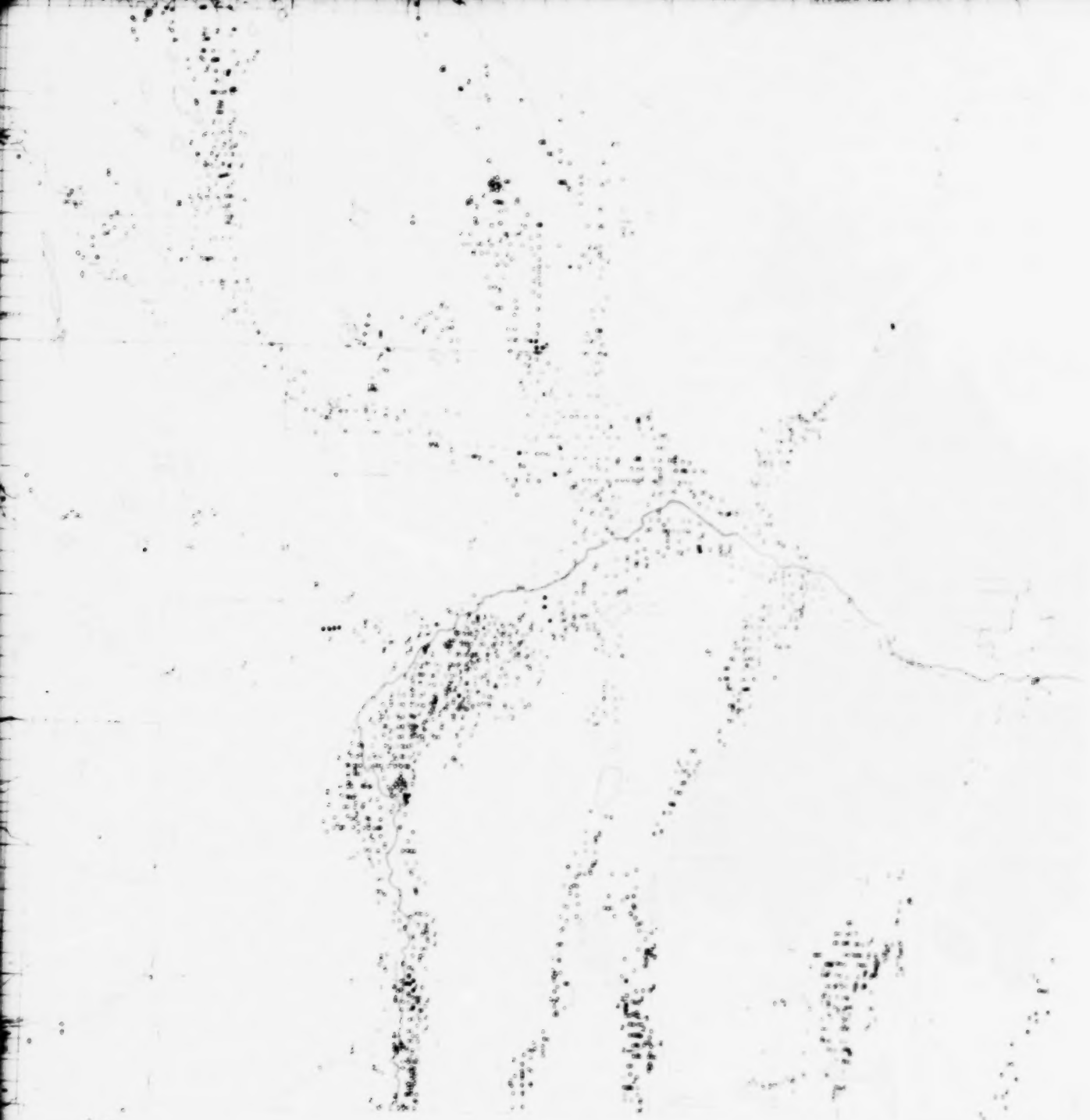
Chemical analyses of water samples collected from selected water wells by the Project are presented in Appendix B. Figures 6 and 7 show that chemical composition of water in the valley-fill aquifers differs widely, even within local areas. In general, total hardness exceeds 200 milligrams per liter (mg/l) and concentrations of total dissolved solids and sulfate exceed the recommended upper limits of 500 mg/l and 250 mg/l respectively of the U. S. Public Health Drinking Water Standards (21).

TABLE I

USE OF WATER WELLS

Use	Boulder County	Larimer County	Logan County	Morgan County	Sedgwick County	Washington County	Weld County	Total Wells
Irrigation	44	417	361	1264	147	41	2789	5063
Stock	20	57	130	158	30	118	267	780
Domestic	1195	702	320	332	44	17	647	3257
Commercial	26	17	7	25	--	6	16	97
Municipal	12	3	22	17	13	--	29	96
Industrial	7	4	36	30	6	1	30	114
Domestic and Stock	9	10	26	105	2	41	45	238
Other	1	--	--	1	--	--	--	2
Total Wells	1314	1210	902	1932	242	224	3823	9647

LEGEND
Dune Sand
Valley-fill Deposits
MIDDLE BASIN
LOWER BASIN



LEGEND

Dune Sand

Valley-fill Deposits

- Irrigation well
- Public supply well
- Industrial well
- Domestic well
- Stock well
- Unused well

SOUTH PLATTE RIVER BASIN PROJECT

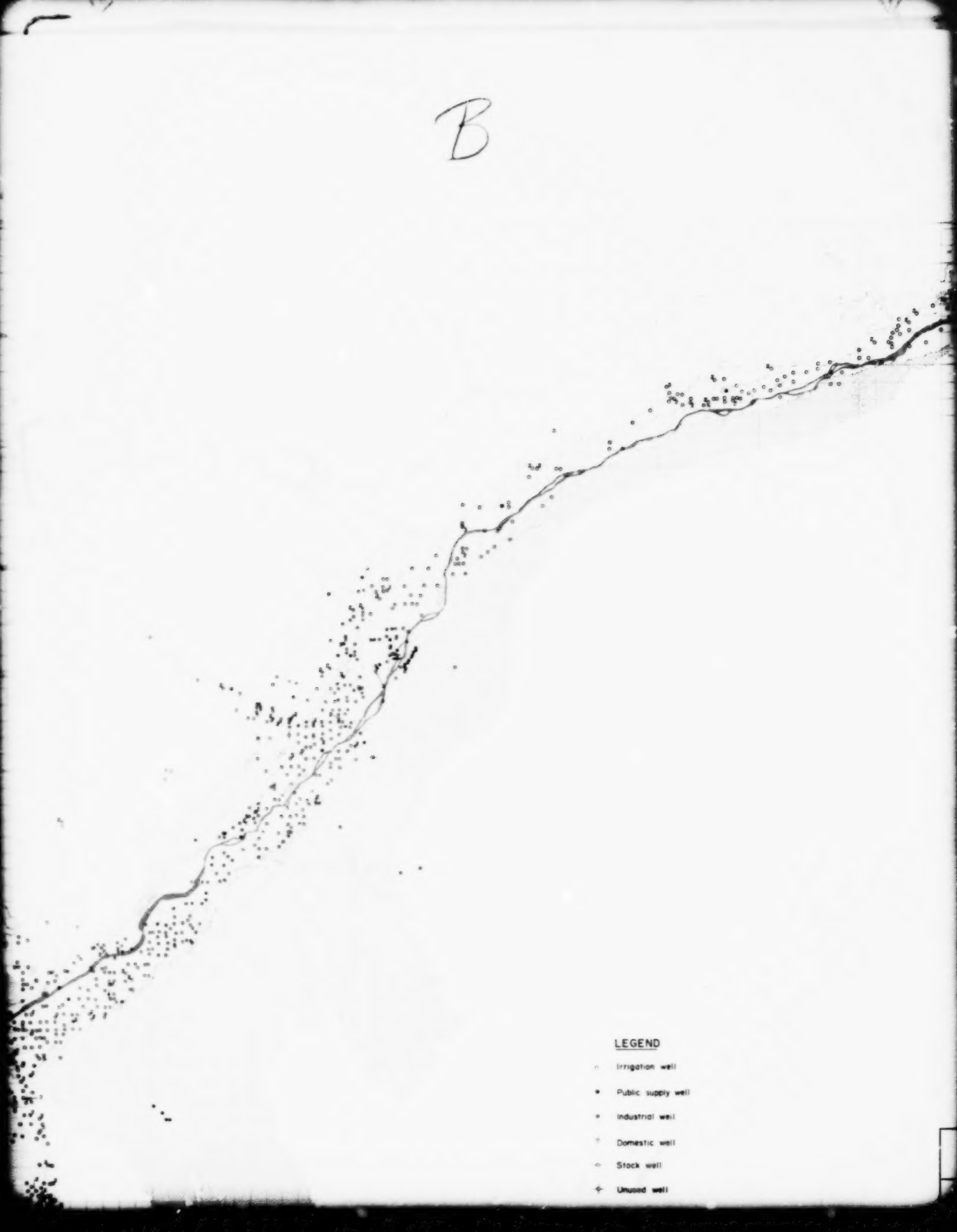
LOCATION OF SELECTED WATER WELLS TAPPING THE VALLEY-FILL AQUIFERS MIDDLE BASIN

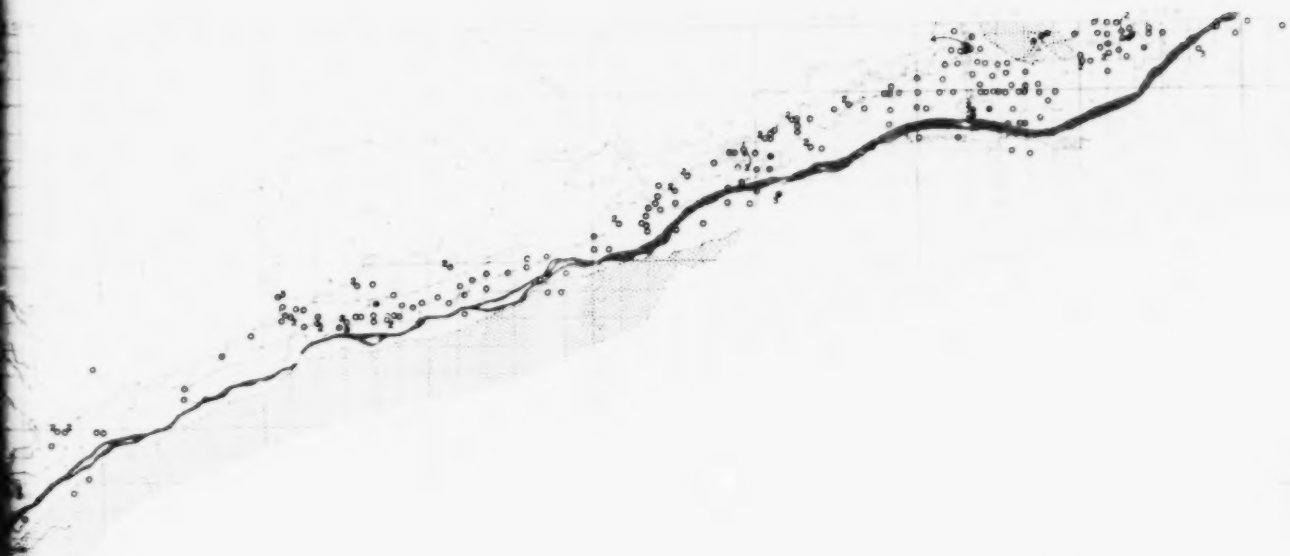
U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration

Denver, Colorado

FIGURE 4

B


LEGEND
Irrigation well
Public supply well
Industrial well
Domestic well
Stock well
Unused well

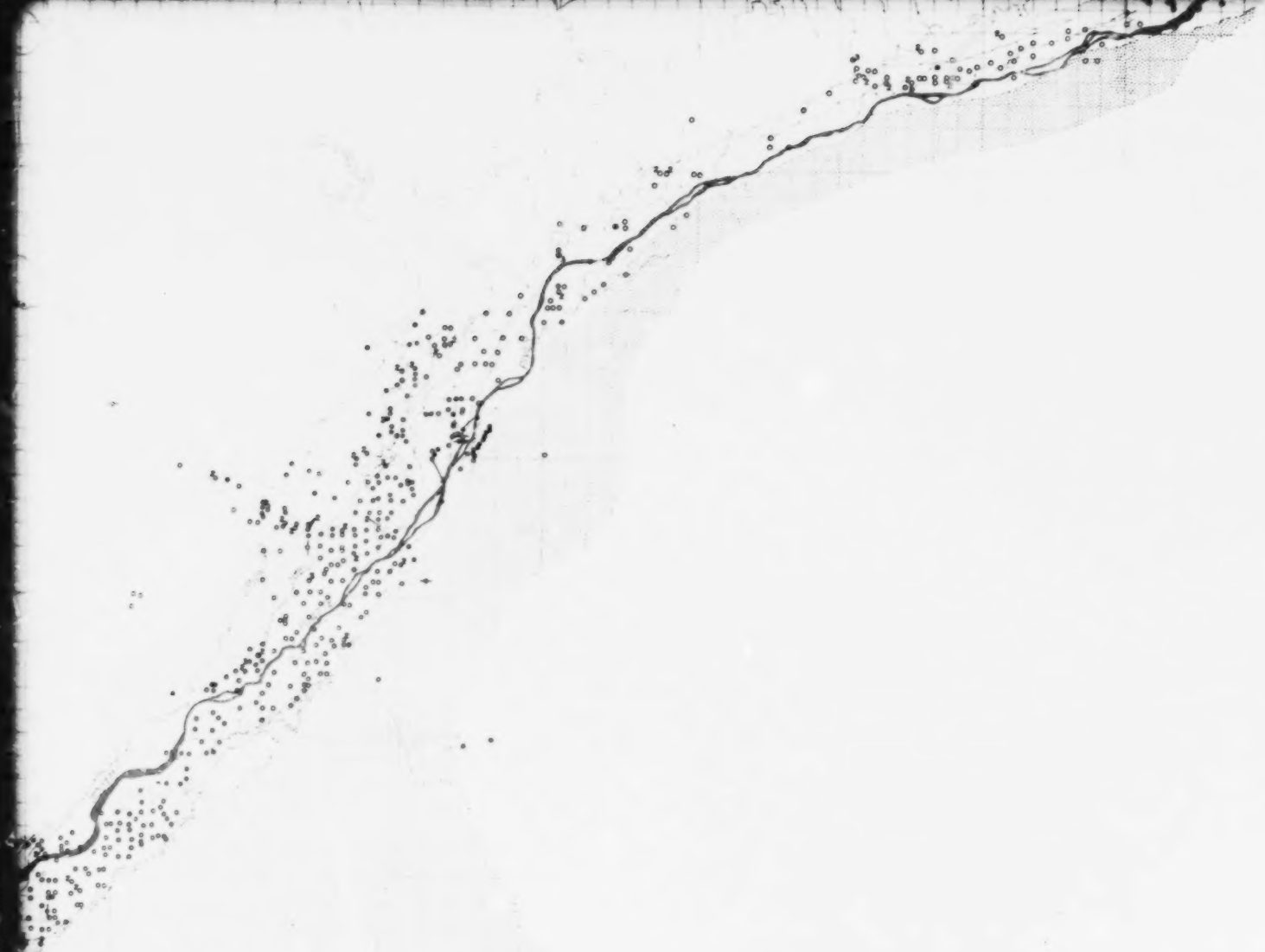


LEGEND

- Irrigation well
- Public supply well
- Industrial well
- Domestic well
- Stock well
- Unused well

SOUTH PLATTE RIVER BASIN PROJECT

LOCATION OF SELECTED WATER WELLS



LEGEND

- Irrigation well
- Public supply well
- Industrial well
- Domestic well
- Stock well
- Unused well
- Dune Sand
- Valley-fill Deposits

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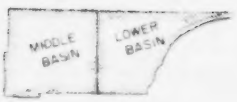

LEGEND

- Irrigation well
- Public supply well
- Industrial well
- Domestic well
- Stock well
- Unused well
- Dune Sand
- Valley-fill Deposits

SOUTH PLATTE RIVER BASIN PROJECT

LOCATION OF SELECTED WATER WELLS TAPPING THE VALLEY-FILL AQUIFERS LOWER BASIN

U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration

Denver, Colorado

FIGURE 5

9-7

TABLE II

MUNICIPAL WATER SYSTEMS SUPPLIED BY WELLS

County	Municipality or Water District	Estimated Population in 1965	Number of Water Wells	Geologic Source	Estimated Pumpage in 1965 (Acre-Feet)
Boulder	Nederland	348	1	Valley-fill	130
	Base Line W. D.	400	1	Valley-fill	45
	Wagoner W. D.	320	10	Valley-fill	62
Larimer	Wellington	600	3	Valley-fill	205
Logan	Crook	230	1	Valley-fill	77
	Iliff	210	1	Valley-fill	49
	Merino	268	2	Valley-fill	93
	Peetz	225	4	Ogallala-White River	70
	Sterling	11,500	14	Valley-fill	3,613[a/]
Morgan	Brush	4,000	4	Valley-fill	724[a/]
	Log Lane Village	400	2	Valley-fill	62
	Fort Morgan	8,100	11	Valley-fill	2,347[a/]
Sedgwick	Julesburg	1,875	5	Valley-fill	487[a/]
	Ovid	544	4	Valley-fill	89[a/]
	Sedgwick	276	4	Valley-fill	68[a/]
Weld	Dacono	350	2	Fox Hills	47
	Eaton	1,300	2	Valley-fill	410
	Firestone	300	3	Fox Hills	131
	Fort Lupton	2,250	4	Valley-fill	599
	Grover	125	2	Fox Hills-Laramie	41
	Hudson	495	2	Valley-fill	144
	Keenesburg	409	3	Fox Hills-Laramie	123
	Kersey	430	2	Valley-fill	103
	LaSalle	1,085	2	Valley-fill	287
	Nunn	217	2	Valley-fill	62
	Pierce	430	3	Valley-fill	101
	Platteville	625	2	Valley-fill	125
	Totals	37,312	96		10,294

a/ Metered

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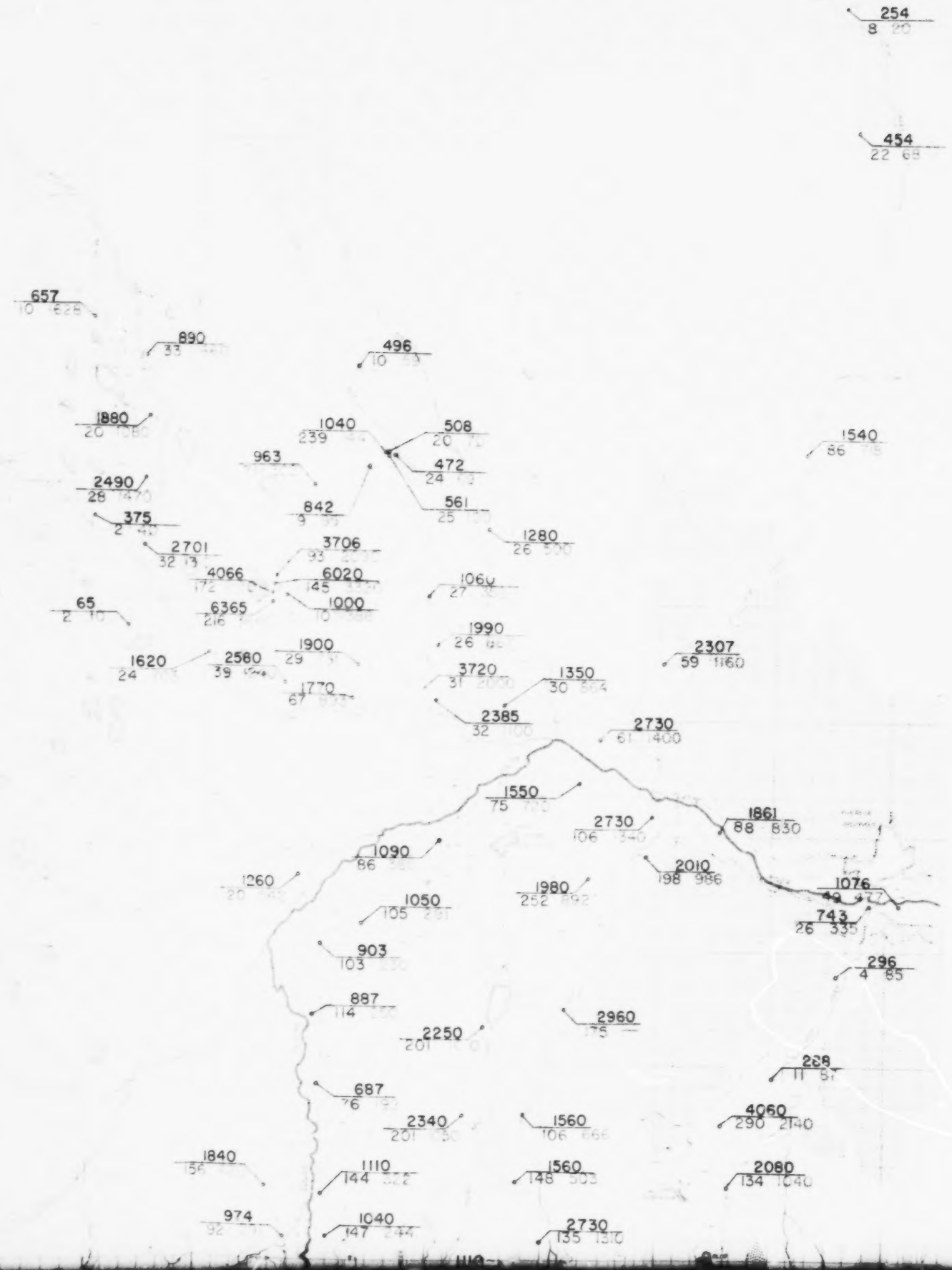
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830
2730
106
1090
86
2010
198
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1260
1980
252
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1050
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903
103
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4
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887
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2960
2250
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974
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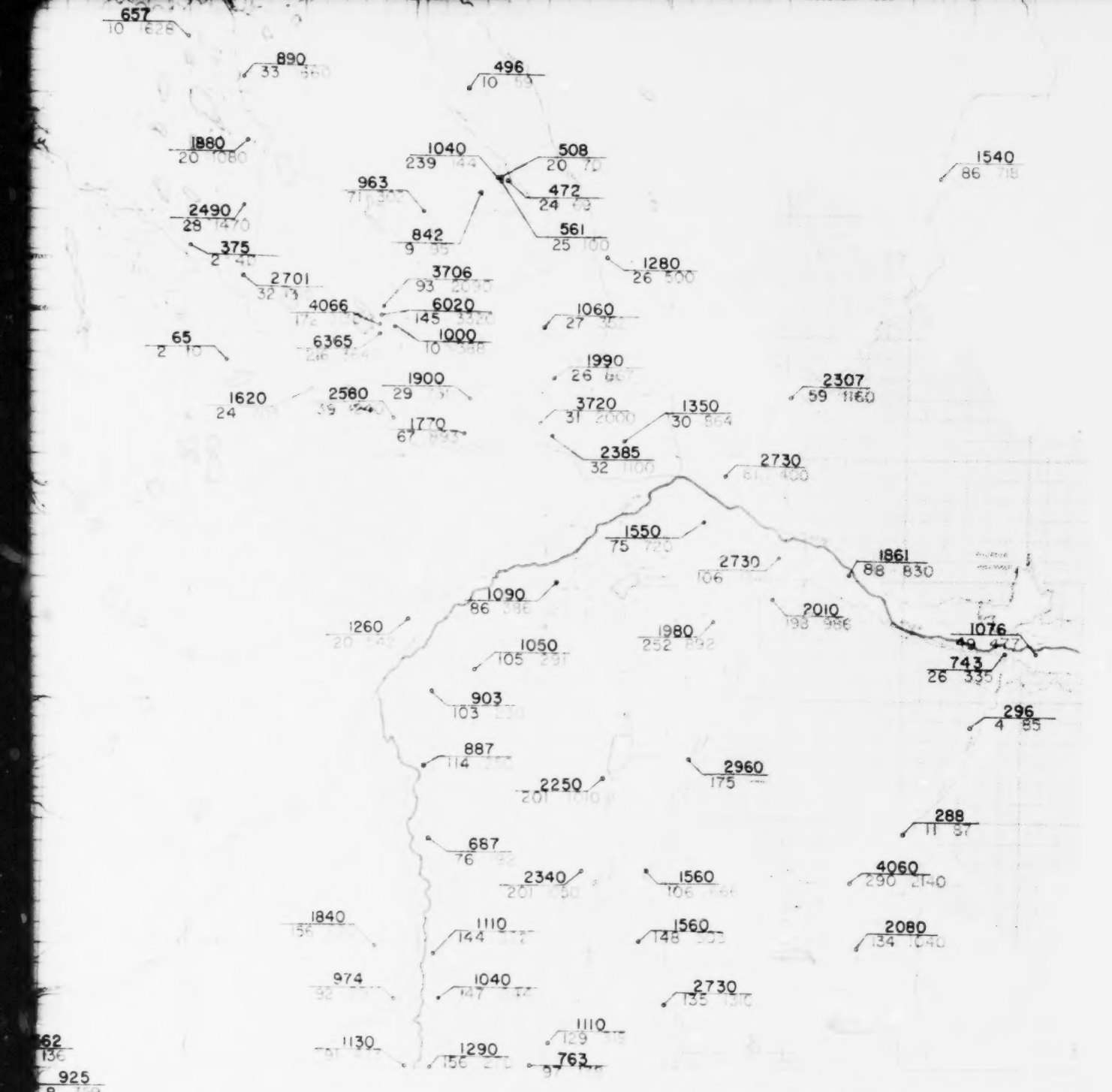
268
562
925
44
LEGEND
Total Dissolved Solids
(mg/l)
Dune Sand
Valley-fill Deposits
MIDDLE BASIN
LOWER BASIN



LEGEND

Total Dissolved Solids (mg/l)

Dune Sand

Valley-fill Deposits

SOUTH PLATTE RIVER BASIN PROJECT

TOTAL DISSOLVED SOLIDS, CHLORIDE, AND SULFATE CONCENTRATIONS IN WATER FROM WELLS TAPPING THE VALLEY-FILL AQUIFERS MIDDLE BASIN

U S DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration

Denver, Colorado

FIGURE 6

10-66

1960
2050
80
1530
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1630
64 893
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1070
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1420
61 675
1550
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1130
41 519
1480
51 752
904
36
1180
51
2540
410
112
45

B

LEGEND

Total Dissolved Solids (mg/l)
Chloride Sulfate

SOUTH PL

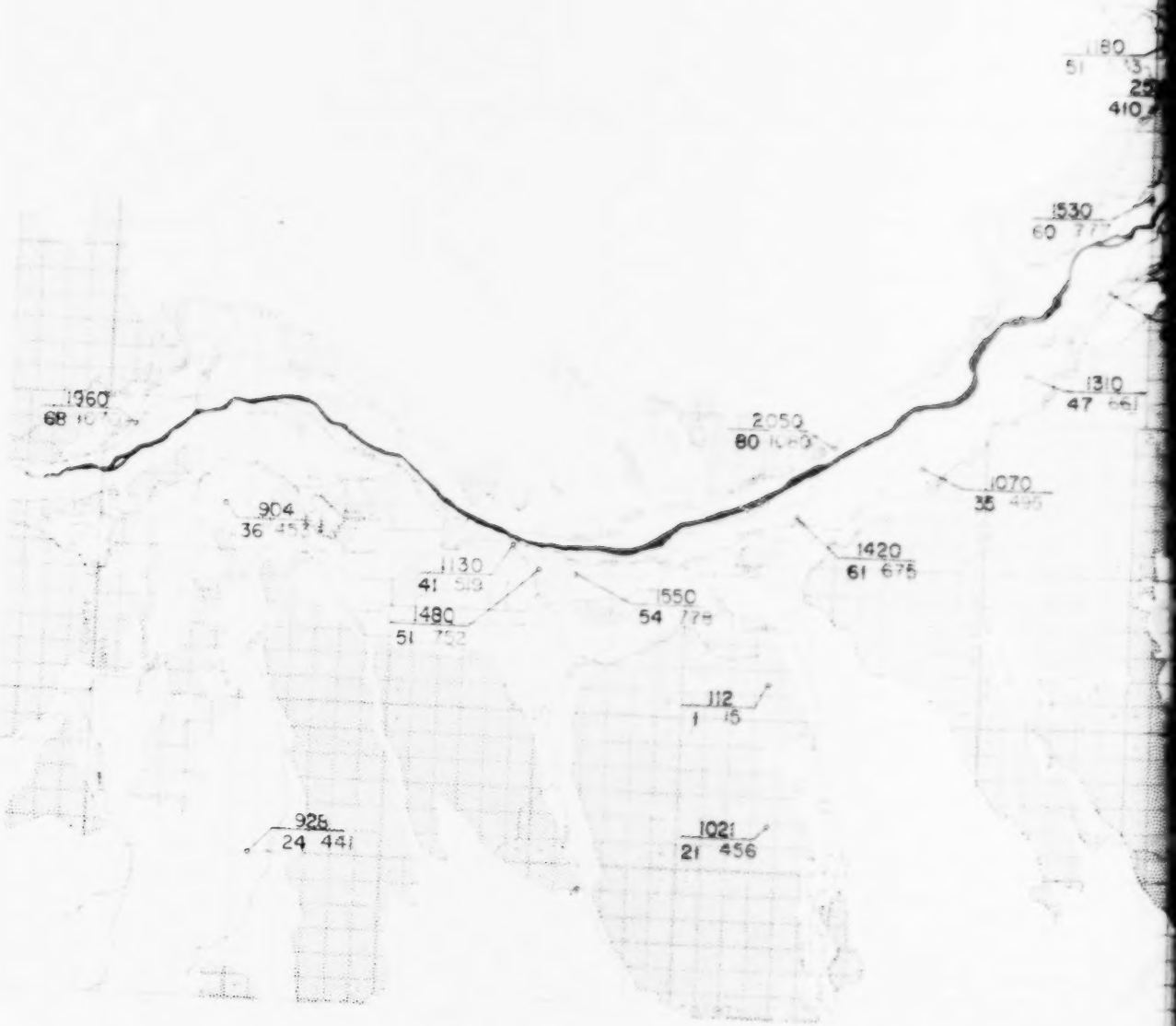
TOTAL DISSOL

LEGEND

Total Dissolved Solids (mg/l)
Chloride
Sulfate

SOUTH PLATTE RIVER BASIN PROJECT

TOTAL DISSOLVED SOLIDS, CHLORIDE, AND SULFATE CONCENTRATIONS IN WATER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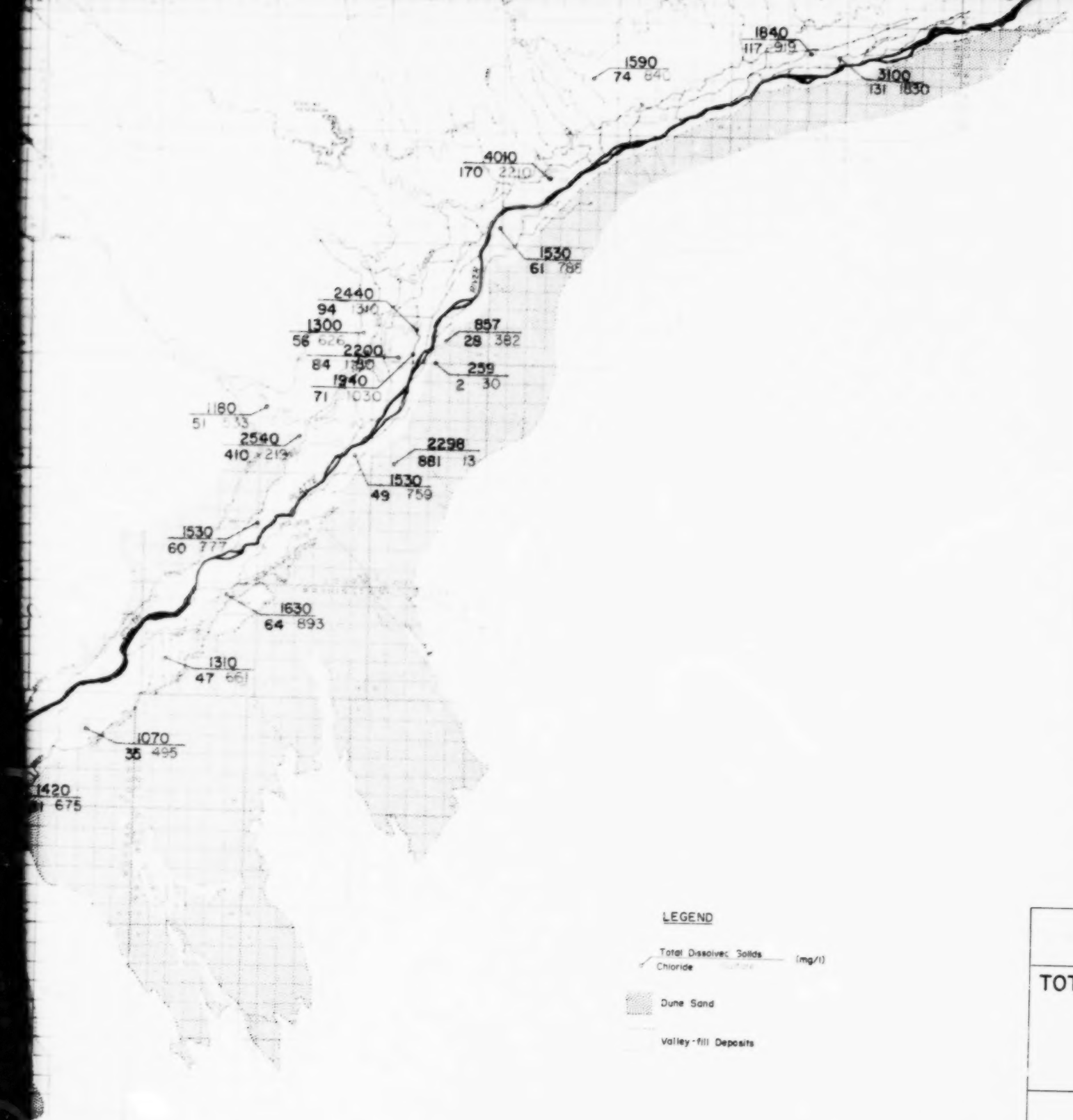
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61 788
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94 1310
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2200
84 1190
1940
71 1030
857
28 382
259
2 30
1180
51 713
2540
410 x 219
2298
881 13
1530
49 759
1530
60 777
1630
64 893
1310
47 661
1070
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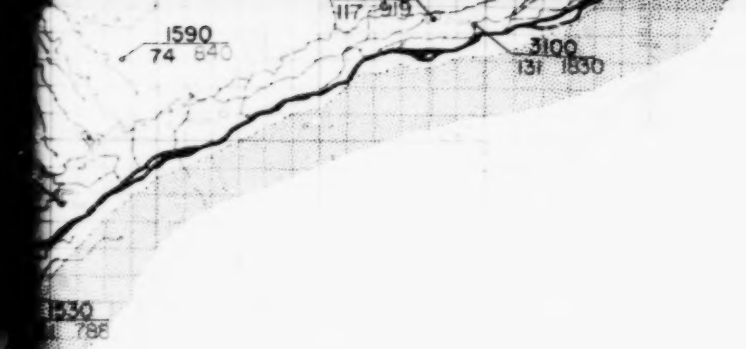
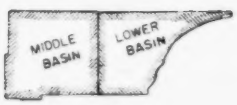
1420
675
LEGEND
Total Dissolved Solids (mg/l)
Chloride
Dune Sand
Valley-fill Deposits

TOTAL
SUL





LEGEND

Total Dissolved Solids (mg/l)
Chloride

Dune Sand

Valley-fill Deposits

SOUTH PLATTE RIVER BASIN PROJECT

TOTAL DISSOLVED SOLIDS, CHLORIDE, AND SULFATE CONCENTRATIONS IN WATER FROM WELLS TAPPING THE VALLEY-FILL AQUIFERS LOWER BASIN

U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration

Denver, Colorado

FIGURE 7

E

10-b

F

In the main South Platte River valley between the southern Weld County line and the Town of Gilcrest, water in the valley-fill aquifer is predominantly of the calcium bicarbonate type. Total dissolved solids range from 687 to 1840 mg/l, bicarbonate from 236 to 460 mg/l, sulfate ranges from 182 to 329 mg/l, and chloride from 76 to 156 mg/l. Significant amounts of nitrate (NO_3) and alkyl benzene sulfonate (ABS) occur in the shallow ground water throughout most of this locality and will be discussed in subsequent sections of this report. Downvalley from Gilcrest to the State line, the shallow ground water in the main valley increases in mineralization and changes to predominantly calcium sulfate or sodium sulfate types of water. Total dissolved solids normally range from 743 to 4010 mg/l, and sulfate from 329 to 2210 mg/l. Chloride concentrations tend to decrease, normally ranging about 35 to 170 mg/l, but are commonly less than 75 mg/l.

In the heavily pumped areas of the southern tributary valleys of Weld County, the shallow ground water is predominantly high in mineralization. In Box Elder Creek valley, total dissolved solids commonly exceed 1500 mg/l and range up to 2960 mg/l. In the Prospect Valley area of Lost Creek valley, total dissolved solids commonly exceed 1000 mg/l and range up to 4060 mg/l. The relatively high mineralization in the northern part of the Prospect Valley area is due largely to the continued recycling of ground water by pumping. In the southern part of the Prospect Valley area, the ground water is lower in mineralization and its chemical quality determined largely by recharge from storm runoff and by seepage of South Platte River water into the aquifer. Good quality ground water occurs in the less developed parts of some southern tributary valleys in Morgan County. The City of Brush obtains its water supply from a well field tapping the valley-fill deposits of lower Beaver Creek Valley; total dissolved solids in this water average only 119 mg/l.

The valley-fill aquifers in the northern tributary valleys of Lodgepole Creek and upper Crow Creek contain waters having less than 400 mg/l total dissolved solids. In the heavily developed irrigated areas of lower Crow Creek valley, total dissolved solids of the shallow water commonly exceed 2000 mg/l. In the valleys of Lone Tree and Spring Creeks of northwestern Weld County, mineralization increases downvalley from about 500 mg/l total dissolved solids near the town of Nunn to about 2000 mg/l in the lower end of Lone Tree Creek valley.

Poor quality ground water occurs in valley-fill deposits underlying the lower Cache la Poudre drainage in northwestern Weld and northeastern Larimer counties. In the heavily irrigated areas north of the Cache la Poudre River, total dissolved solids generally exceed 2000 mg/l and sulfate concentrations commonly exceed 1200 mg/l. Sulfates are primarily attributed to the presence of soluble evaporite materials, mainly gypsum, in the shallow water-bearing formations (6)(22).

Water quality data are not available over a continuous period of time for assessing long-term changes in mineralization of ground water in the valley-fill deposits. Since 1964, the U. S. Geological Survey

has established approximately 100 sampling sites in the middle and lower South Platte River Basin. The chemical quality of water in the valley-fill aquifer in the main valley is determined largely by the chemical quality of river water diverted for irrigation use. Comparison of chemical analyses of ground waters with those of river waters (4)(23-34) show similar concentrations of total dissolved solids, chlorides, and bicarbonate. A close relationship is indicated between surface waters entering the Basin and waters in the valley-fill aquifers.

Mineralization of the ground water in the valley-fill deposits increases in a downvalley direction. Figures 6 and 7 show that the pattern of mineralization of the shallow ground water in the main valley consists of alternating localities of higher and lower degrees of salinity. Ground water in localities having higher degrees of salinity tends to increase in mineralization downvalley primarily due to the reuse cycle of irrigation water. The cycle begins with diversions of river water to irrigation canals, storage reservoirs and irrigated lands, seepage to the unconfined aquifer, movement of this water downvalley through the aquifer and discharging into the River as groundwater return flow; this return flow is again diverted by the next downstream intake canal. This cycle is repeated many times in the South Platte River during its course of travel downstream. Because of the shallow depth of the water table in the valley-fill deposits, evapotranspiration losses account for a large part of the increased mineralization in this water.

Other Aquifers

In the northern part and eastern end of the study area, the water-bearing zones in the White River Group and Ogallala Formation of Tertiary age contain water of good quality. Chemical analyses (5)(17)(33)(34)(35)(36) show total dissolved solids range from about 200 to 450 mg/l with total hardness generally less than 200 mg/l. Poorer quality water is often obtained from wells that produce a mixture of waters from the Tertiary formations and the overlying valley-fill deposits, or from underlying bedrock formations of Cretaceous age.

Chemical quality of waters in the bedrock formations of Cretaceous age varies widely. In general, better quality water occurs in and near the surface exposures of the water-bearing beds and quality becomes poorer with increased depth and distance from areas of recharge. Chemical analyses (4)(5)(6)(17)(34)(35)(36) show that waters from the bedrock formations are generally lower in hardness than waters from the valley-fill aquifers. High sulfate waters commonly occur in the Pierre, Fox Hills, and Laramie formations in northeastern Larimer, north central Weld, and northern Morgan Counties. Sulfates are primarily attributed to the presence of gypsum deposits or gypsiferous shales.

GROUND-WATER POLLUTION

The unconfined aquifers in the middle and lower South Platte River Basin are very susceptible to contamination from polluted water or other liquids discharged onto the land surface. Unconfined ground water occurs chiefly in the valley-fill deposits, dune sand deposits, Ogallala Formation, White River Formation, Precambrian crystalline rocks, and the outcrop areas of the sedimentary bedrock formations of Cretaceous age.

Saline Water

The middle and lower South Platte River Basin is an important petroleum producing area in Colorado. One hundred and eighty-five oil and gas fields were located throughout the area in 1966. These fields produced approximately 7 million barrels of oil and 17.3 billion cubic feet of gas in 1966, accounting for about 21 and 12 percent respectively of the total State production during this period (37).

Petroleum is produced primarily from wells tapping the deeper beds of Cretaceous age, including the "D", "J", and "O" sandstone units of the Dakota Group, and some limestone and sandstone members of other Cretaceous formations. Petroleum is also produced from the Lyons Sandstone of Permian age. Depths of the petroleum-bearing formations range from about 3200 to 8500 feet below land surface. Chemical analyses obtained from the files of the Colorado Oil and Gas Conservation Commission show the quality of water associated with many of these petroleum-bearing formations and are given in Appendix C. A summary of these analyses is presented in Table III. The Dakota "D" and "J" sands, which produce about 85 percent of the petroleum in the area, contain predominately sodium chloride or sodium bicarbonate associated waters. Sodium concentrations range from 956 to 4480 mg/l; chlorides from 650 to 7000 mg/l, and commonly exceed 2000 mg/l; bicarbonates from 653 to 3700 mg/l and commonly exceed 1500; total dissolved solids from 2960 to 12,400 and commonly exceed 5000 mg/l. Similar water occurs in the Dakota "O" and "Sussex" producing zones. Highly mineralized water is found in the Lyons Sandstone where chloride and total dissolved solids range up to 56,000 and 96,900 mg/l respectively.

Records of the Colorado Oil and Gas Conservation Commission show oil and gas fields produced about 27 million barrels (3480 acre-feet) of associated water in 1966. These records are based on monthly production reports submitted by petroleum operators. The data represent only an order of magnitude because much water production is not metered and other times not reported. For example, on August 12, 1966, the Project found the Excelsior Oil Corporation's tank battery, located in the Atwood-East Field of Logan County in B7-53-24dada, was discharging about 50 gallons per minute of waste water directly into the South Platte River. The chloride content of this water was 1950 mg/l. The amount of associated water reported from each field in 1966 is shown in Appendix D.

TABLE III

SUMMARY OF CHEMICAL QUALITY OF WATER
ASSOCIATED WITH PETROMEUM-BEARING FORMATIONS[a/]

Geologic Unit	Number of Sampling Stations	Range of Concentration in Milligrams per Liter					
		Chloride (Cl)	Sulfate (SO_4)	Bicarbonate (HCO_3)	Calcium (Ca)	Sodium (Na)	Total Dissolved Solids
Dakota "D"	22	3,300- 7,000	<10- 856	939-3,000	11-1,030	2,660- 4,480	6,920-12,400
Dakota "J"	26	650- 5,530	6- 700	653-3,700	6- 201	956- 4,190	2,960-11,900
Dakota "O"	2	1,810- 2,090	231- 379	1,400-2,270	2- 19	1,980- 2,140	5,980[b/]
Sussex	3	4,580- 4,900	33- 145	930-1,070	24- 41	3,260- 3,630	9,670-10,200
Lyons	12	1,760-56,000	5,960-14,800	315-1,260	86-1,140	4,900-38,100	23,700-96,900

a/ Analyses shown in Appendix C

b/ One sample

Of the total of 149 oil or gas fields reporting information, 31 fields returned a portion of their waste water to petroleum-bearing formations through injection wells used for disposal or secondary recovery purposes. It is concluded that 16 million barrels, or 59 percent of the total produced water in 1966 was returned to petroleum-bearing formations through injection wells; most of the remaining 11 million barrels of produced water was stored in holding ponds.

The approximate location of water-producing oil and gas fields, and the surface exposures of geologic formations occurring in the area are shown in Figures 1 and 2. The surface geology shown on these maps is based largely on geologic and hydrologic maps prepared by the U. S. Geological Survey (4)(5)(6)(17)(38)(39) and other investigators (40). The geologic formations exposed at the land surface in the vicinity of each water-producing oil or gas field in the study area are also listed in Appendix D.

A large number of these oil and gas fields are located in the recharge areas of fresh water-bearing formations. Ninety water-producing oil or gas fields are located in areas covered by unconsolidated materials of dune sand deposits, valley-fill sand and gravels, and the Ogallala Formation. Fifty-six water-producing oil or gas fields are located on the outcrops of the White River Group, Laramie Formation, and Fox Hills Sandstone; formations that contain beds or zones of water-bearing material. Waste water discharged to unlined holding ponds readily enters unconfined aquifers in localities where pits are excavated in permeable rocks. Examples of ground-water pollution caused by saline water from oil and gas fields in the lower and middle South Platte River Basin are described as follows:

In August 1960, Water Well No. 3 (B8-66-27-ada) of the town of Pierce became contaminated by saline water reported as originating from the California Company #1 U.P.R.R-Ferch oil well located 240 feet south of the water well. Chlorides in the well water increased to 879 mg/l (41) from a normal level of about 25 mg/l. Since the source of contamination was quickly discovered, widespread pollution of the valley-fill aquifer did not occur. The water well was restored to normal use after pumping at a high rate until the saline contaminants were removed from the aquifer.

During the study of Pierce area, two water wells which tap the valley-fill aquifer were found to produce unusually high chloride water. A domestic well (B8-66-27abd) and a lawn irrigation well (B8-66-27aac) yielded water having chlorides of 239 and 160 mg/l respectively. Chlorides are attributed to brine pits located north and northwest of the wells. A sample taken from a small brine pit (B8-66-22acc), located about 3500 feet north and upgradient from the water wells, had a chloride content of 21,200 mg/l in July 1965. Disposal pits in this locality are excavated in the sands and gravels of the valley-fill deposits.

A study of ground-water quality conducted by Colorado State University (22) in the Severance area in 1965 showed quality deterioration caused by unlined disposal pits in the New Windsor Oil Field. Samples taken from test holes around a disposal pit located in B7-67-26bcd indicated that saline water was seeping into the underlying Fox Hills Sandstone.

In the Gary-North Field, located about nine miles south of Brush in Morgan County, a shallow stock well (B2-56-22bcc) was reported as abandoned several years ago due to salt water contamination. Waste pits in this field are excavated in dune sand which transmits water directly to the underlying valley-fill deposits. A sample taken from one pit in August 1966 showed a chloride concentration of 5520 mg/l.

In Logan County near the Atwood Field, a sample collected from a domestic well (B7-53-21ccc) revealed a chloride concentration of 410 mg/l. The water well, 40 feet in depth, taps dune sand and valley-fill deposits. A brine disposal pit is located about 500 feet west-southwest of the water well and is excavated in dune sand. A sample taken from this pit in August 1966 showed a chloride concentration of 536 mg/l.

In the Dune Ridge Field of Logan County, about 3 miles southeast of the town of Atwood, the use of unlined holding ponds has affected the quality of the shallow ground water. A stock well (B7-52-32bca) tapping the dune sand and valley-fill deposits at a depth of 60 feet, revealed a chloride concentration of 881 mg/l. Several large holding ponds, excavated in the dune sand, are located about 3500 feet south and upgradient from the well. A sample of pond water revealed a chloride concentration of 1270 mg/l in August 1966.

Because many oil and gas fields are located in remote areas, it is difficult to determine the extent of ground-water pollution from waste disposal ponds. Detailed studies are needed, including the drilling of shallow sampling wells in the vicinity of most petroleum fields. The saline contamination of the valley-fill aquifer in the Rocky Mountain Arsenal area near Denver (42) is an excellent example of the widespread contamination that may result from using unlined waste disposal ponds.

The construction of petroleum wells is often inadequate insofar as providing optimum protection of fresh water-bearing formations from contamination by deeper saline water-bearing formations penetrated in the same borehole. In most instances, surface casings of petroleum production or exploratory wells are set and cemented only through the near-surface coarse rock formations. Smaller diameter casings or liners are set and cemented in the remaining portion of the borehole penetrating finer-grained sediments which may contain both fresh water and saline water-bearing formations. The deeper saline waters may enter the fresh water formations through defective liners. The liner is susceptible to leakage from corrosion because of inherent construction problems of

setting and cementing long strings of liner; a continuous cement bond between the liner and borehole is seldom achieved. Available data (43) indicate the bottoms of petroleum well surface casings often occur above the fresh water-bearing zones of the White River Group, Laramie Formation, Fox Hills Sandstone, and Pierre Shale. Detailed studies are needed to determine the depth, thickness, and extent of the fresh water-bearing zones in these formations. A firm basis must be established for requiring proper surface casing depths of petroleum wells under the provisions of the General Drilling Rules established by the Colorado Oil and Gas Conservation Commission (44).

Alkyl Benzene Sulfonate

Significant concentrations of ABS occur throughout most of the valley-fill aquifer in the main valley of the South Platte River upstream from the town of Hardin as illustrated by Figure 8. The highest levels of widespread occurrence of ABS are in the main valley upstream from the town of LaSalle where ABS concentrations range from 0.1 to 0.5 mg/l and commonly exceed 0.2 mg/l. ABS was also found throughout the Beebe Seep drainage area and in the upper reaches of the southern tributary valleys of Box Elder Creek and Lost Creek. Significant quantities of ABS were also detected in the valley-fill aquifers in many small localized areas in the main South Platte River valley downstream from Hardin and in the western and northern tributary valleys as shown in Figures 8 and 9.

ABS was found to be present in the following municipal well water supplies: Fort Lupton, Platteville, Gilcrest, LaSalle, Kersey, Hudson, Nunn, Pierce, and Eaton in Weld County; Wellington in Larimer County, and Merino in Logan County. ABS was also detected in the well waters of Wagoner Water District and Baseline Water District in Boulder County. These data are tabulated in Appendix B. It is important to note that none of the municipal well waters in the study area exceeded the recommended upper limit of 0.5 mg/l ABS as defined by the U. S. Public Health Drinking Water Standards (21).

The principal source of ABS in the main valley, the southern tributary valleys of Beebe Seep, upper Box Elder Creek, and upper Lost Creek was recharge water originating from sewage treatment plants in the Denver Metropolitan area. An inventory of municipal waste discharges conducted by the Project in 1965 (45) showed 23 sewage treatment plants discharged about 105 million gallons per day (mgd) to the surface streams in the Denver Metropolitan area. Although the manufacture of ABS type detergents was discontinued in June 1965, much of the pollution of ground water by ABS will persist for several decades in the future.

Septic tank effluents have contributed significant amounts of ABS to unconfined aquifers in populated localities that are not served, or only partially served, by sewage treatment facilities. The effects of septic tanks as shown by Figures 8 and 9 are most apparent in the suburban areas immediately east of the City of Boulder and in or near the

following towns: Wellington in Larimer County; Nunn, Pierce, Eaton, Severance, and Hereford in Weld County; and Merino in Logan County.

ABS was also detected in waters from domestic wells near the City of Estes Park, located in the Front Range mountains of Larimer County. Many water wells in this area tap the crystalline rocks of Precambrian age. The presence of ABS in these waters indicates contamination by septic tank effluents and is of particular concern. The voids of the crystalline rocks are chiefly large fractures which provide little filtration of bacteria. Records of the Colorado State Engineer (16) show there are 325 domestic water wells within the outcrop of crystalline rocks in the Front Range mountains of Boulder and Larimer counties (see Figure 1). The many domestic wells provide water to residences, restaurants, motels, and recreational facilities.

Nitrate

The U. S. Public Health Service Drinking Water Standards (21) recommend that nitrate (NO_3) concentrations in water should not exceed an upper limit of 45 mg/l. Water containing excessive amounts of nitrate is potentially dangerous when used for infant feeding.

Figures 10 and 11 show that nitrate concentrations greater than 20 mg/l generally occur in the heavily irrigated sectors overlying the valley-fill aquifers of the South Platte River and its tributaries. Nitrate concentrations less than 20 mg/l are generally found in the non-irrigated uplands or in stream valleys with realtively little irrigated farm land. Figure 10 specifically indicates very high nitrate levels throughout most of the main valley of the South Platte River upstream from the town of Kersey and the lower end of the Cache la Poudre Valley. Nitrate levels in the shallow ground water of these two areas are predominantly greater than 35 mg/l and frequently greater than 45 mg/l.

Many municipal well waters in the middle and lower Basin contain significant nitrate verified by Project data in Table IV. These municipal wells all tap the valley-fill deposits with the exception of Peetz which produces water from Ogallala and White River formations. The wells serving the communities of Fort Lupton, LaSalle, Gilcrest, and Nunn within Weld County, consistently provide water with more than 45 mg/l nitrate. Twelve municipal systems utilize well water with nitrate levels between 20 mg/l and 45 mg/l. These systems include: the Wagoner Water District in Boulder County; Wellington in Larimer County; Peetz and Sterling in Logan County; Fort Morgan in Morgan County; Julesburg and Sedgwick in Sedgwick County; and Hudson, Platteville, Kersey, Eaton, and Pierce in Weld County.

Sources of nitrates in the valley-fill aquifers include fertilizers applied on irrigated farms, sewage-laden water diverted from streams and feedlot operations. A major portion of nitrates to the

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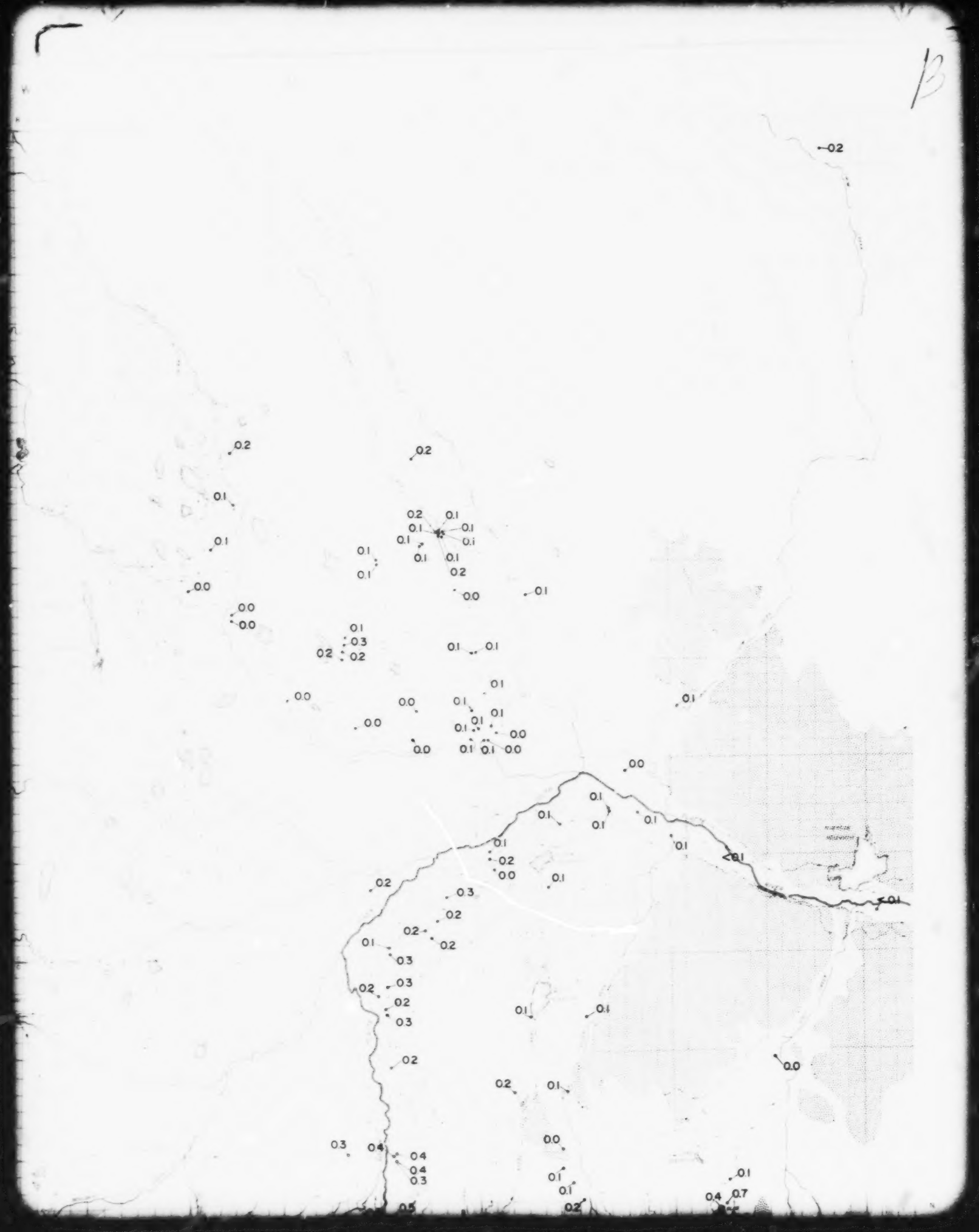
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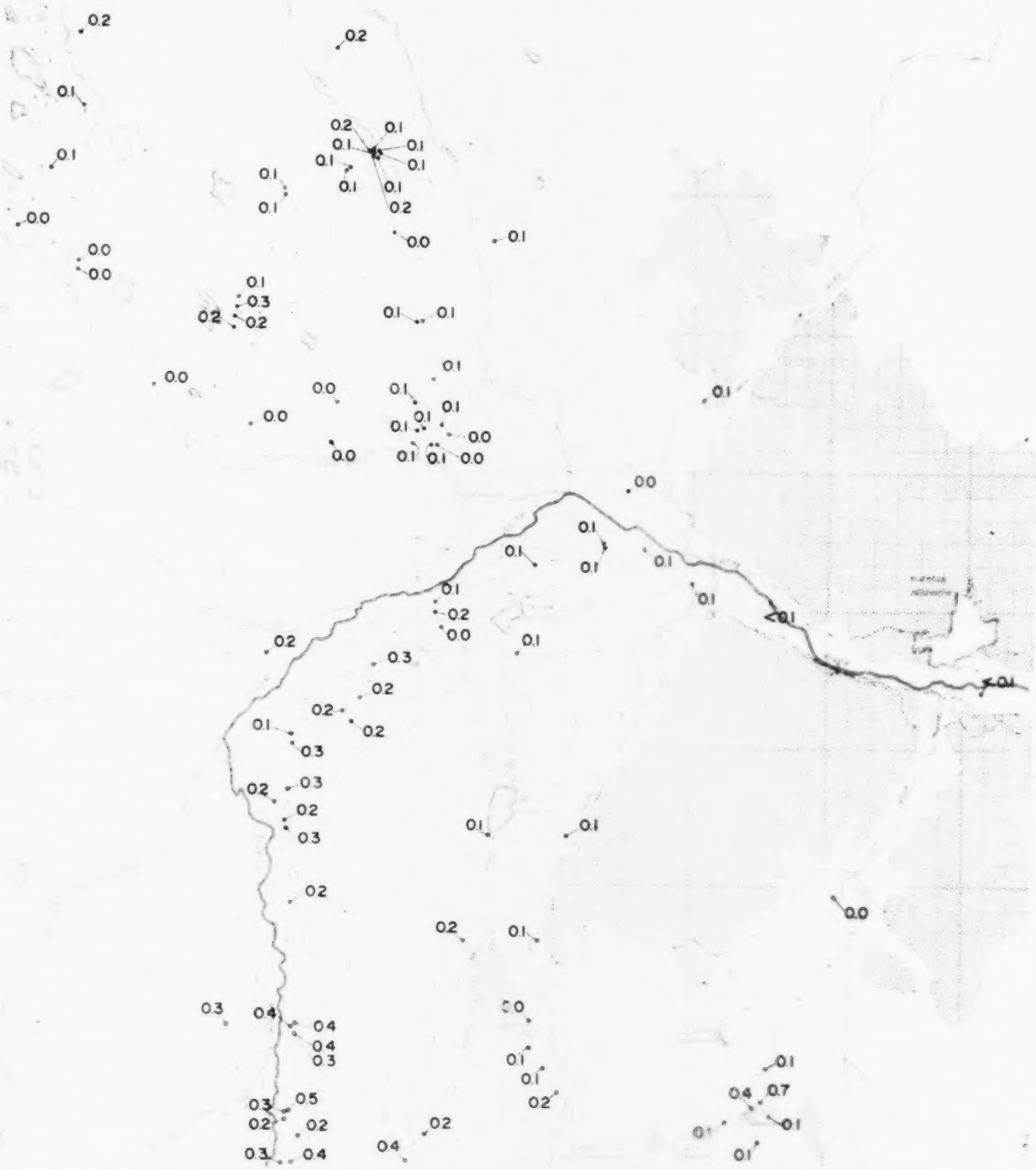
LEGEND
ABS, mg/l
Dune Sand
Valley-fill Deposits
MIDDLE BASIN
LOWER BASIN



LEGEND

ABS, mg/l

Dune Sand

Valley-fill Deposits

SOUTH PLATTE RIVER BASIN PROJECT

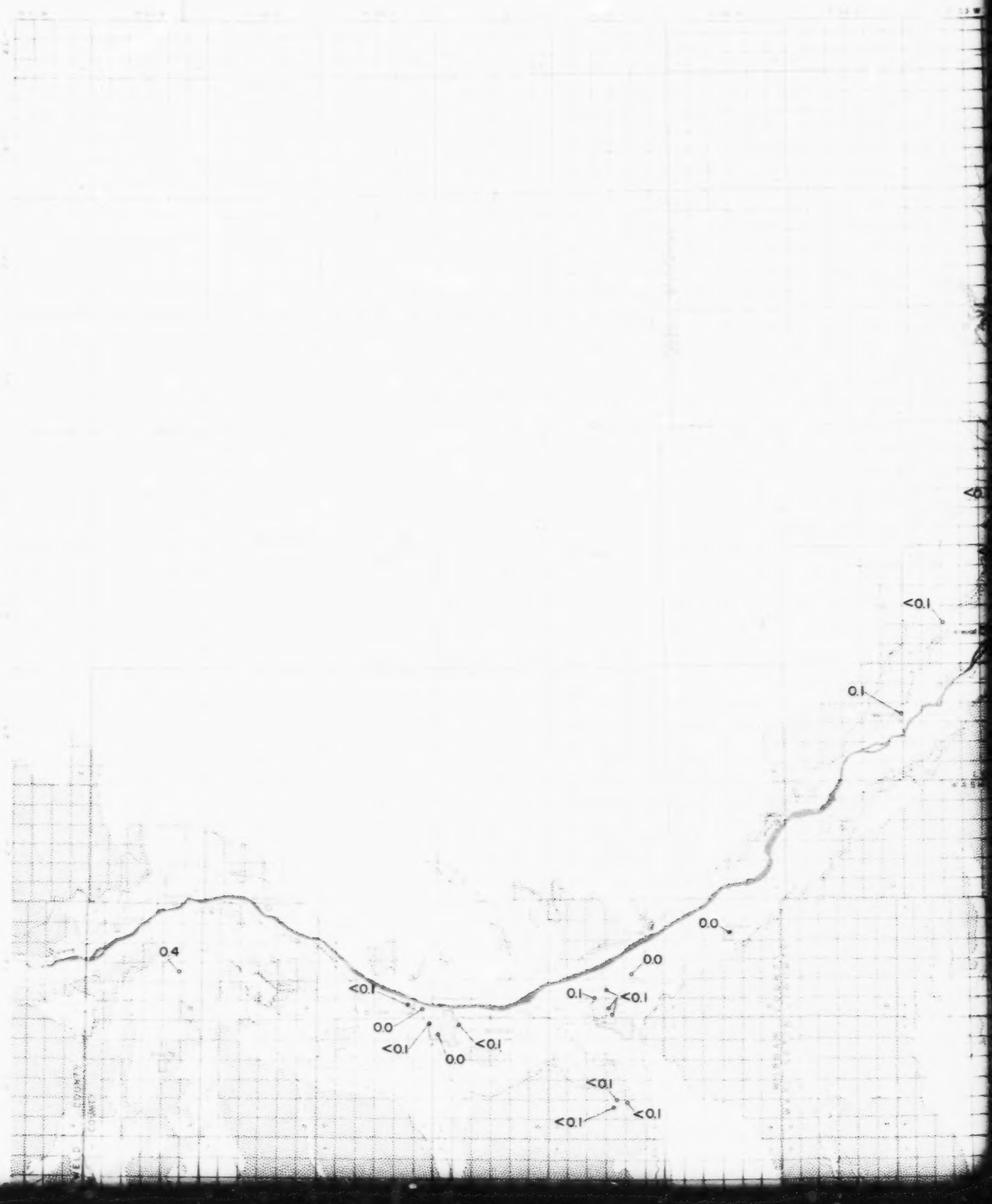
ABS CONCENTRATIONS IN WATER FROM WELLS TAPPING THE VALLEY-FILL AQUIFERS MIDDLE BASIN

U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration

Denver, Colorado

FIGURE 8

18-cc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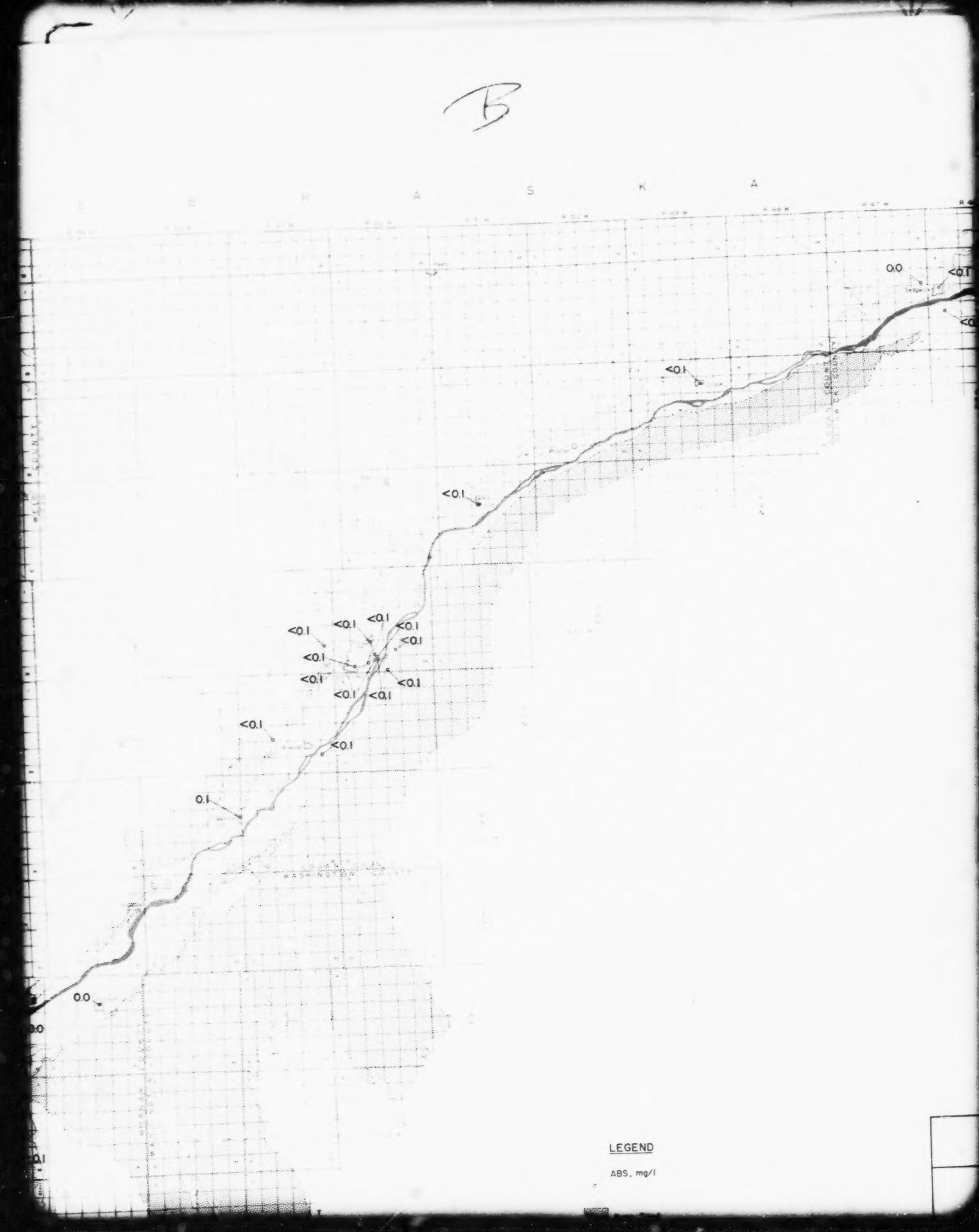
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ABS, mg/l

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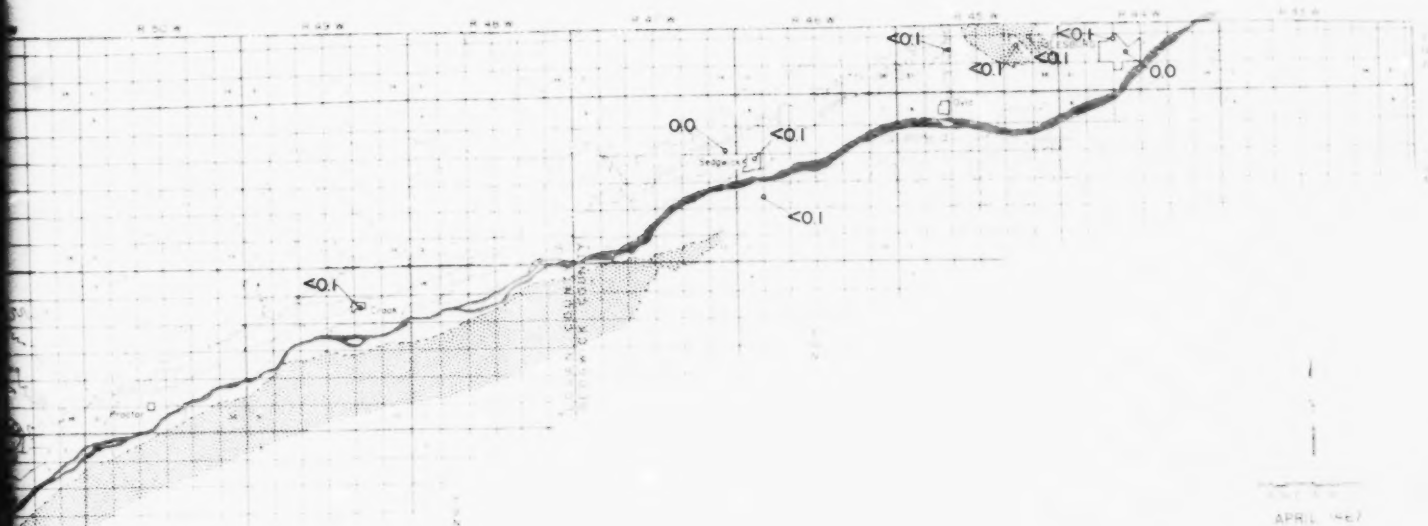

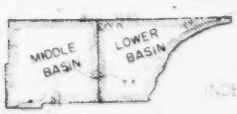

INDEX MAP

LEGEND

ABS, mg/l

SOUTH PLATTE RIVER BASIN PROJECT

ABS CONCENTRATIONS IN WATER

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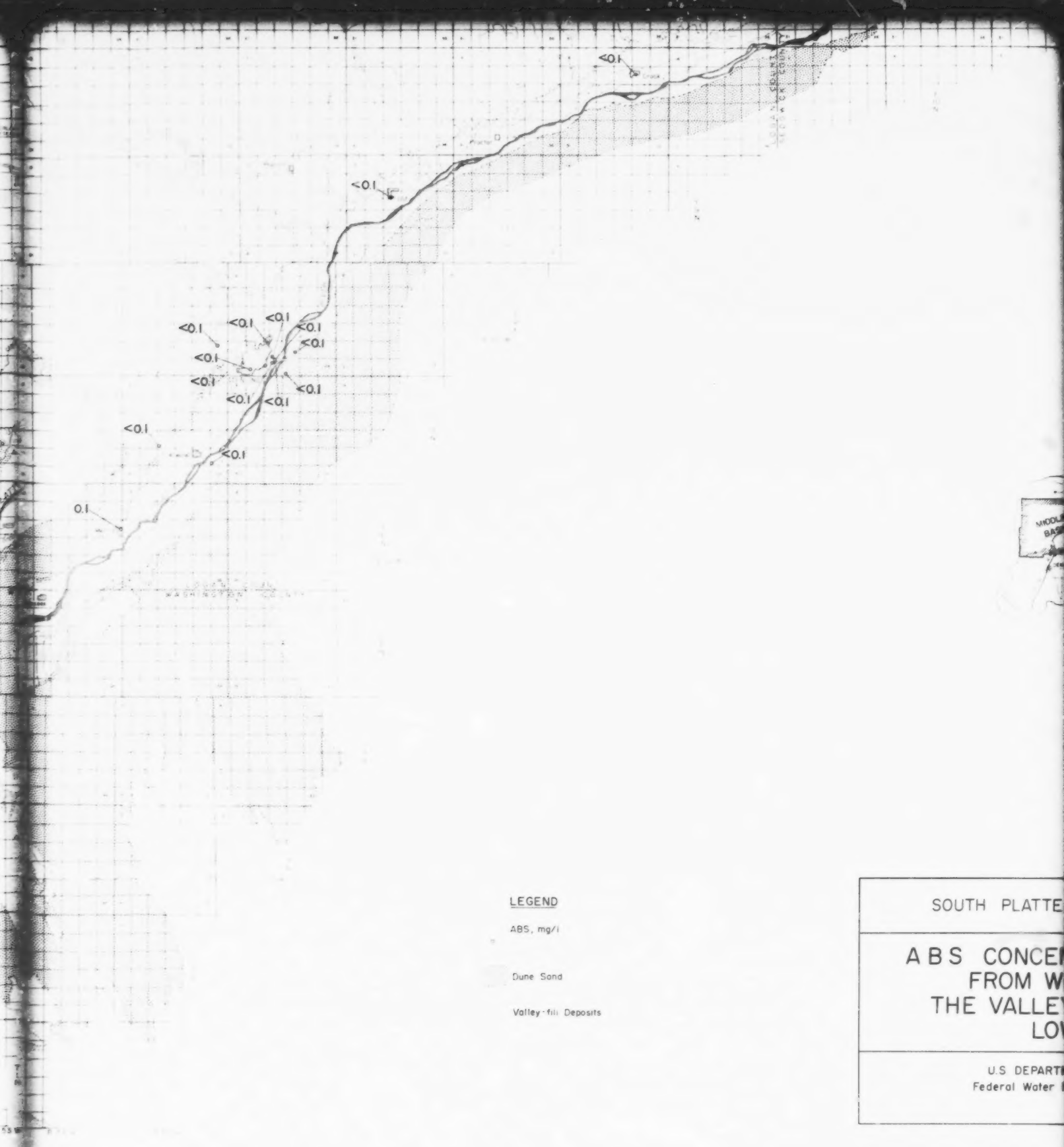

LEGEND

ABS, mg/l

Dune Sand

Valley-fill Deposits

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Federal Water

18

LEGEND

ABS, mg/l

Dune Sand

Valley-fill Deposits

SOUTH PLATTE RIVER BASIN PROJECT

ABS CONCENTRATIONS IN WATER FROM WELLS TAPPING THE VALLEY-FILL AQUIFERS LOWER BASIN

U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration

Denver, Colorado

FIGURE 9

18-C

LEGEND
Dune Sand
Valley fill Deposits
Feedlot

LEGEND

Dune Sand

Valley fill Deposits

Feedlot

NO_3 less than 20 mg/l

NO_3 between 20 and 45 mg/l, incl

NO_3 greater than 45 mg/l

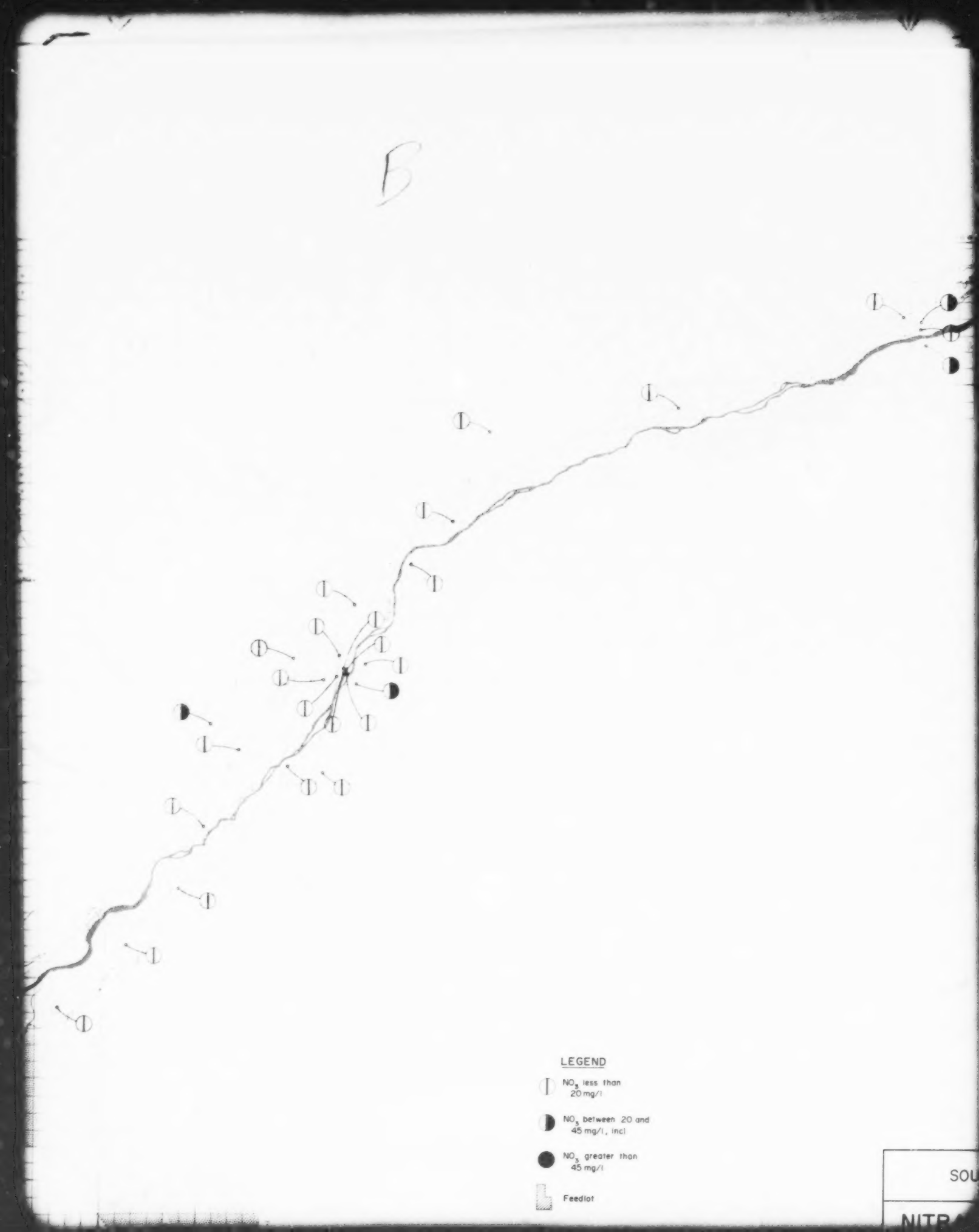
SOUTH PLATTE RIVER BASIN PROJECT

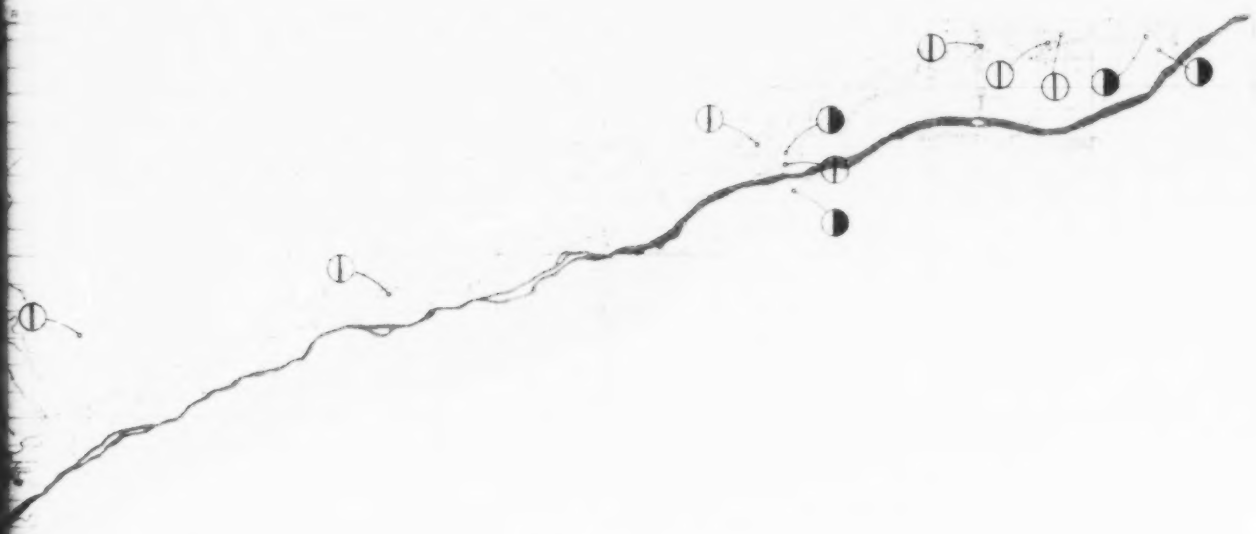
NITRATE CONCENTRATIONS IN WATER FROM WELLS TAPPING THE VALLEY-FILL AQUIFERS MIDDLE BASIN

U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration

Denver, Colorado

FIGURE 10


LEGEND
NO_3 less than 20 mg/l
NO_3 between 20 and 45 mg/l, incl
NO_3 greater than 45 mg/l
Feedlot

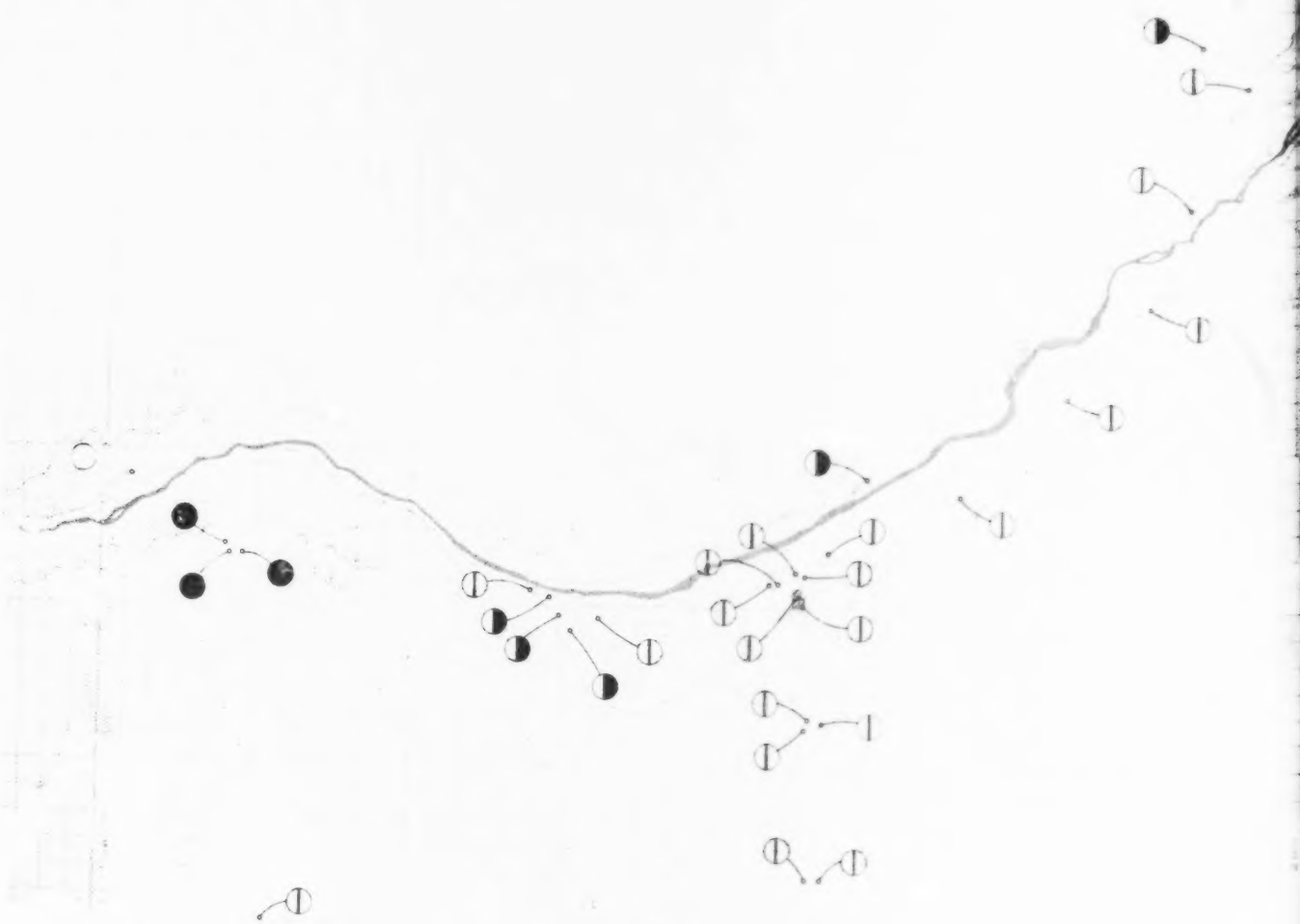


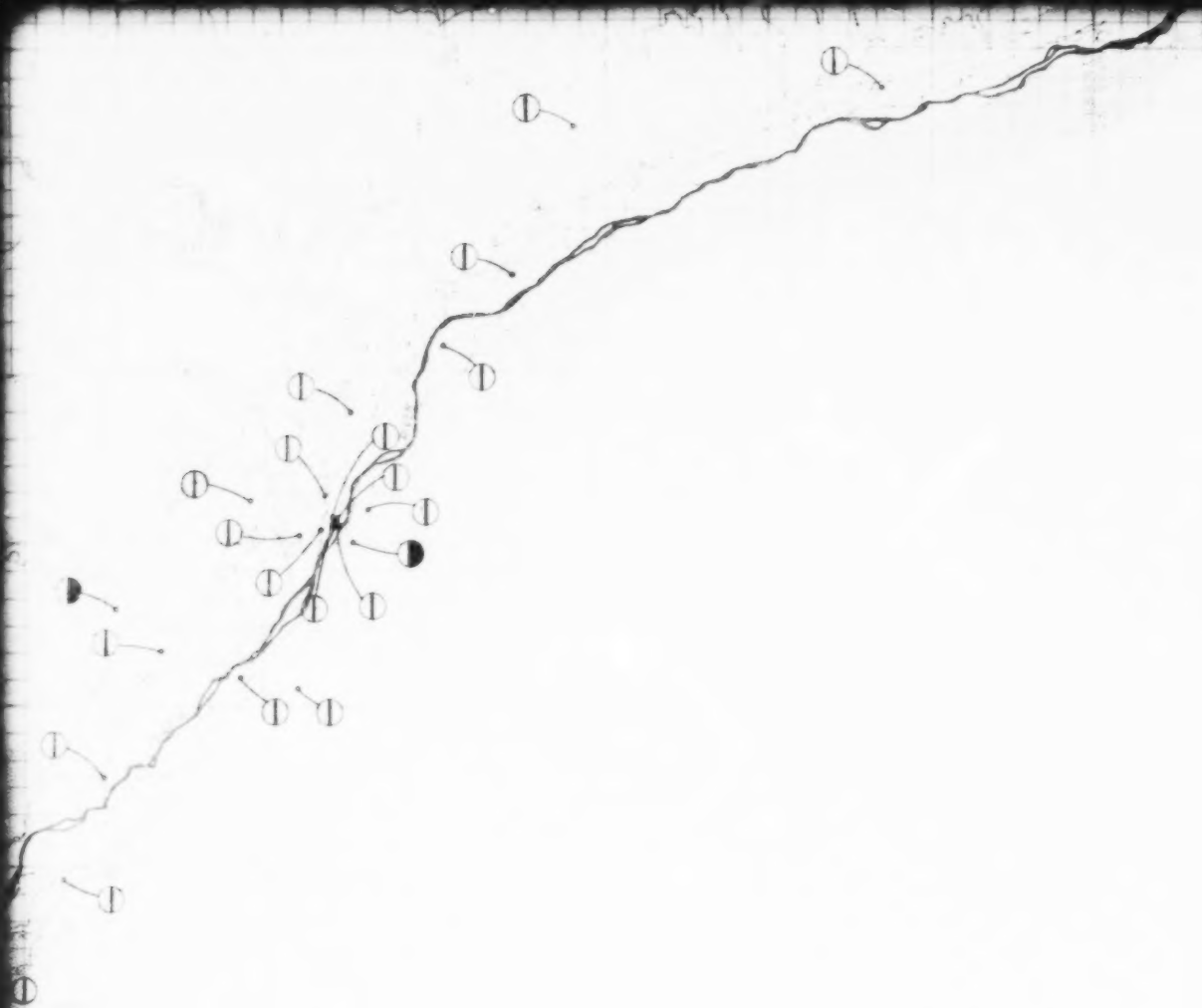
LEGEND

- NO_3 less than 20 mg/l
- NO_3 between 20 and 45 mg/l, incl
- NO_3 greater than 45 mg/l
- Feedlot

SOUTH PLATTE RIVER BASIN PROJECT

NITRATE CONCENTRATIONS IN WATER





LEGEND

- NO_3 less than 20 mg/l
- NO_3 between 20 and 45 mg/l, incl
- NO_3 greater than 45 mg/l
- Feedlot
- Dune Sand
- Valley-fill Deposits

SOUTH PLATTE R

NITRATE CONCENT
FROM WEL
THE VALLEY-
LOWER

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Federal Water Pollu

Denv

6

18-

LEGEND

- NO_3 less than 20 mg/l
- NO_3 between 20 and 45 mg/l, incl
- NO_3 greater than 45 mg/l
- Feedlot
- Dune Sand
- Valley-fill Deposits

SOUTH PLATTE RIVER BASIN PROJECT

NITRATE CONCENTRATIONS IN WATER FROM WELLS TAPPING THE VALLEY-FILL AQUIFERS LOWER BASIN

U.S. DEPARTMENT OF THE INTERIOR
Federal Water Pollution Control Administration

Denver, Colorado

FIGURE 11

18-d

TABLE IV

NITRATE CONCENTRATIONS IN WATER FROM SELECTED MUNICIPAL WELLS

County	City, Town or Water District	Well Location (T-R-Sec)	Well Depth (ft)	Sampling Date	Nitrate (mg/l)
Boulder	Wagoner W. D.	B1-70-33dba	20 [a]	6-23-65	32
Larimer	Wellington (#1)	B9-68-33aaa	43	5-15-65	22
Logan	Peetz	B11-51-6bba	145	8- 9-66	38
	Peetz	B11-51-6bba	240	8- 9-66	33
	Peetz	B11-51-6bbd	375	8- 9-66	21
	Sterling (#8)	B8-52-34cbc	65	7-13-66	28
	Sterling (#9)	B8-52-34ccb	71	7-13-66	27
	Sterling (#10)	B8-52-34ccd	80	7-13-66	24
Morgan	Fort Morgan	B3-57- 6adc	189	7-27-66	21
	Fort Morgan	B3-57- 6add	211	7-27-66	21
	Fort Morgan	B3-57- 6bdd	175	7-27-66	25
	Fort Morgan	B3-57- 6cdc	179	7-27-66	22
	Fort Morgan	B3-57- 6dbb	250	7-27-66	23
	Fort Morgan	B3-57- 8bbd	175	7-27-66	25
	Fort Morgan	B3-58- 1adb	253	7-27-66	36
	Fort Morgan	B3-58- 1daa	217	7-27-66	35
	Fort Morgan	B3-58- 1ddb	230	7-27-66	27
	Fort Morgan	B4-58-36caa	93	7-26-66	21
Sedgwick	Julesburg	B12-44-29aad	108	7-26-66	35
	Julesburg	B12-44-29adb	--	7-26-66	22
	Sedgwick	B11-46-18abc	42 [b]	7-26-66	27
	Sedgwick	B11-46-19daa	21 [b]	7-26-66	31

[a] 850 ft. gallery
[b] Composite of 3 wells

TABLE IV
(Continued)

County	City, Town, or Water District	Well Location (T-R-Sec)	Well Depth (ft)	Sampling Date	Nitrate (mg/l)
Weld	Eaton (#1)	B7-65-31cba	--	5-17-65	33
	Eaton (#2)	B7-66-36dab	--	5-17-65	28
	Fort Lupton (#3)	B1-66- 6aaa	55	5-12-65	56
	Fort Lupton (#4)	B1-66- 6abd	50	5-12-65	42
	Fort Lupton (#1)	B1-66- 6daa	57	5-12-65	47
	Fort Lupton (#2)	B1-66- 6daa	55	5-12-65	39
	Gilcrest (#1)	B4-66-28adc	98	5-13-65	105
	Gilcrest (#2)	B4-66-28adc	98	5-13-65	108
	Hudson	B1-65-11aaa	47	6-14-65	26
	Hudson	B2-65-35ddd	60	6-14-65	35
	Kersey (#1)	B5-64-21bca	39	7- 1-65	32
	Kersey (#2)	B5-64-21bbc	67	7- 1-65	30
	LaSalle (#4)	B4-65- 6aba	66	5-13-65	53
	LaSalle (#3)	B5-65-31dbd	63	5-13-65	49
	Nunn (#1)	B9-66-33cac	39	5-13-65	160
	Nunn (#2)	B9-66-33cbd	55	5-13-65	98
	Pierce (#1)	B8-66-26bbc	40	5-17-65	28
	Pierce (#2)	B8-66-26bca	37	5-17-65	32
	Pierce (#3)	B8-66-27ada	41	5-17-65	25
	Platteville (#1)	B3-66-19bdb	57	5-12-65	27
	Platteville (#2)	B3-66-19cab	57	5-12-65	27

unconfined aquifers originates from large-scale commercial fertilizer application (42)(46)(47)(48). Commercial fertilizers consist of many types of nitrate, phosphate, and sulfate compounds. Annual nitrogen requirements in the Basin range up to about 100 pounds per acre. Nitrogen contents of bulk compounds vary from about 10 to 50 percent by weight and total application of bulk commercial fertilizers range from 50 to 300 pounds per acre. Liquid anhydrous ammonia fertilizer is also used extensively in the area.

Sewage-laden water originating from the Metropolitan Denver area contributes significant quantities of nitrate to the valley-fill aquifer, mostly in the main valley receiving irrigation water between Denver and Kersey. Areas of widespread ABS pollution are generally correlated with high nitrate levels. The amounts of nitrate derived from sewage-laden waters are difficult to determine from available data since most records do not include the ammonium and nitrite forms of nitrogen. These forms are probably converted to nitrate after the sewage-laden water seeps into the valley-fill deposits.

Feedlot operations are likely responsible for appreciable amounts of nitrate found in the unconfined aquifers over local areas. However, this source is not believed a principal cause of widespread nitrate pollution. Most feedlots are located in areas of intensive irrigation and respective nitrogen contributions cannot be accurately determined. Project study in 1964 and 1965 showed 37 feedlots each having a population of more than 500 animals (18), were located in the middle and lower South Platte River. From 170,000 to 240,000 head of cattle and sheep were confined within these feedlots, ranging in size from 2 to 240 acres. Localized ground-water pollution can occur owing to the accumulation of large quantities of manure and silage, subject to leaching from rainfall, waste water, and urine. The Project study indicated that much of the liquid wastes are retained on the feedlots in sumps or natural depressions. These wastes are released to the streams by intermittent pumping or infrequently flushed out during periods of intensive rainfall. However, a significant portion of the waste material probably enters the shallow unconfined aquifers beneath most of the feedlots in the area.

Selected water wells were sampled in the vicinity of five large feedlots as illustrated in Figures 10 and 11. The feedlots include: the National Food Stores facility five miles south of the City of Fort Lupton in B1-66-31; the George Mancini facility located four miles south of Fort Lupton in B1-66-30; the Monfort facility located one mile north of Greeley in B6-65-30; the Weisbart feedlots near Brush in B4-56-34; and the Sonnenberg feedlot near Sterling in B8-52-27. From 5,000 to 75,000 head are held in the respective lots and all facilities are located on the valley-fill deposits. Depths to the water table below the sites range from 3 to 40 feet, and thicknesses of the saturated valley-fill deposits range from about 40 to 110 feet. Sampling of shallow wells around these feedlots could not provide data on nitrate contribution because of relatively large additions of nitrate in the ground-water inflow from adjacent parts of the aquifer. However, nitrate

pollution attributable to feedlot wastes was found near the Carl Felte feedlot one mile west of the town of Severance in B7-67-34. In this case, water from a nearby well (B7-67-34ddd) was found to have increased from 5 mg/l nitrate content in 1961 (6) to 46 mg/l in 1965. The 25-foot well is located about 100 feet downgradient from the 3-acre feedlot which holds about 700 cattle. Valley-fill deposits in the vicinity of the feedlot average about 8 feet in saturated thickness, are composed chiefly of fine-grained sediments, and the water table lies about 12 feet below the land surface.

Other Contaminants

Well water supplies obtained from the unconfined valley-fill aquifers are inherently very susceptible to contamination from any nearby waste source. Most shallow municipal wells in the Basin are located within heavily populated townsites and often subject to pollution from careless waste disposal practices. For example, 1.4 mg/l of oil was found in the water produced from the town of Platteville's Well No. 1 (B3-66-19bdb) in June 1965, and 33 mg/l of oil was detected in January 1966. The cleaning and maintenance facility of a road-building contractor was located only a few feet from the water well. Oily wastes were discharged onto the ground and seeped directly into the shallow unconfined aquifer which was tapped by Platteville's well.

Municipalities should adopt a program of monitoring the quality of their water supplies. Besides the distribution system, each water supply well should be sampled on a minimum monthly basis for chemical and bacteriological quality. Waste disposal practices must be controlled in and around townsites and the planning of new well locations should consider the direction and rate of ground-water flow from potential sources of contamination.

GLOSSARY

Aquifer. A stratum, formation or group of formations, which is porous, permeable, and water-bearing and has hydraulic continuity.

Artesian Aquifer. An aquifer that is confined both above and below by a relatively impermeable layer, so that ground water is under sufficient hydrostatic pressure to rise above the aquifer containing it, but which does not necessarily rise above the land surface.

Formation. Any assemblage of rocks which have some character in common, whether of origin, age, or composition, and that can be mapped.

Hydraulic Gradient. The slope or rate of vertical change of the water table or piezometric surface.

Lithology. The composition and texture of rocks. The study of rocks.

Outcrop. That part of a geologic stratum which is exposed at the land surface.

Permeable. A term used to describe rocks having interconnected openings that permit water to move through them perceptibly.

Permeability, Coefficient of. A measure of formation's capacity to transmit water expressed as the rate of flow of water in gallons per day through a cross-sectional area of one square foot under a unit hydraulic gradient.

Piezometric Surface. An imaginary surface that everywhere coincides with the static level of water in an aquifer. The surface to which the water from an aquifer will rise under its own head.

Recharge. The process by which water is added to an aquifer, whether by natural or artificial means.

Transmissibility, Coefficient of. The rate of flow of water in gallons per day through a vertical strip of an aquifer one foot wide extending the full saturated height of the aquifer under a unit hydraulic gradient.

Unconfined Aquifer. Water-bearing material in which the upper surface of its zone of saturation (water table) is either exposed directly to the atmosphere or overlain by unsaturated permeable rocks.

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APPENDIXES

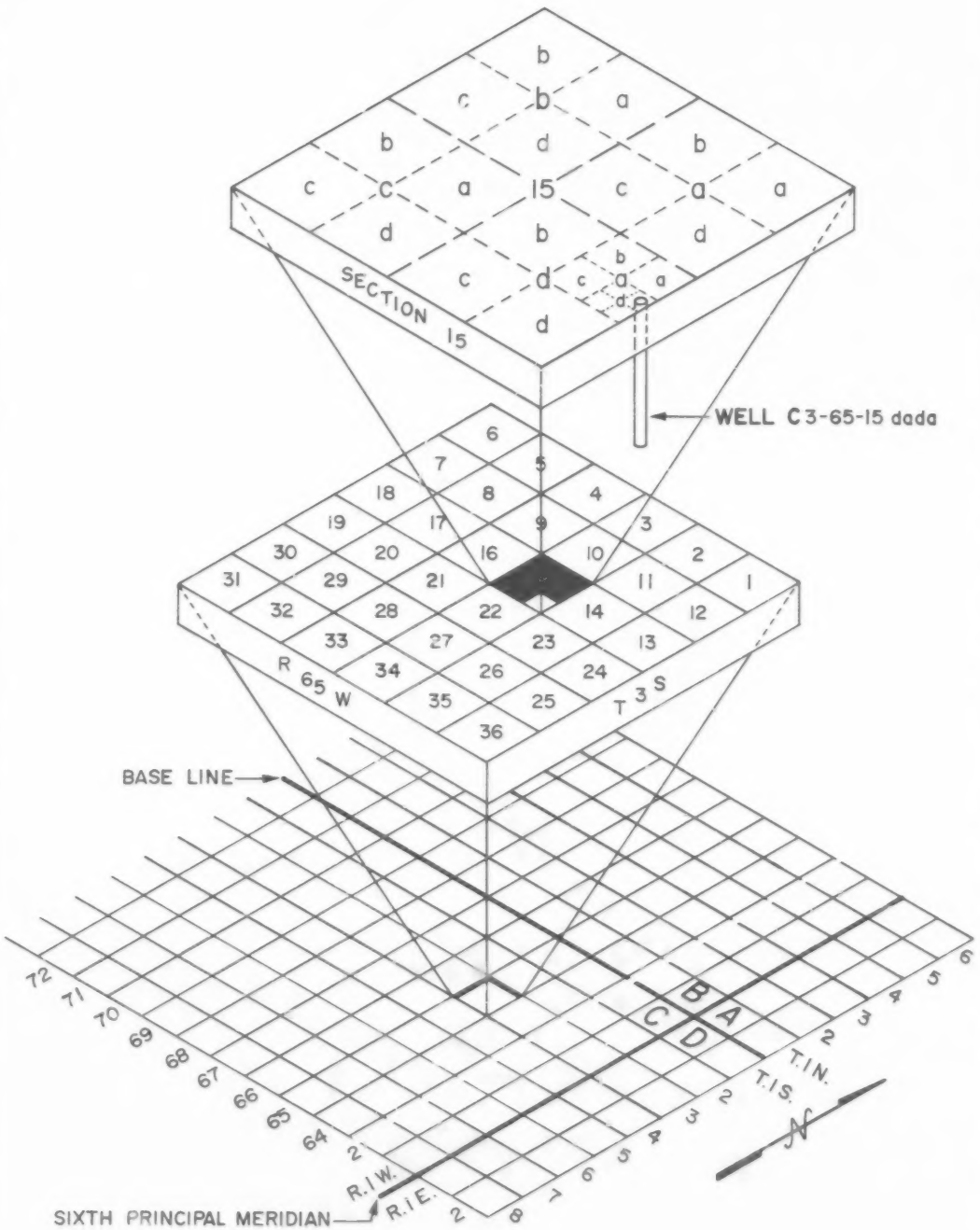
APPENDIX A

SYSTEM OF NUMBERING WELLS AND SAMPLING POINTS

Locations of wells, some sampling points and features in this report are described by using a numbering system based on the U. S. Bureau of Land Management's system of land subdivision. A graphical illustration of this method of site location is shown on the following page.

The capital letter at the beginning of the location number indicates the quadrant in which the well is located. Four quadrants are formed by the intersection of the base line and the sixth principal meridian. "A" indicates the northeast quadrant, "B" indicates the northwest, "C" indicates the southwest, and "D" indicates the southeast quadrant. The township in which a well is located is indicated by the first numeral of the location number, the range by the second numeral, and the section by the third numeral. Lower case letters following the section number indicate the position of the well within the section. The first letter denotes the quarter section, the second letter the quarter-quarter section, the third letter the quarter-quarter-quarter section, and the fourth letter the quarter-quarter-quarter-quarter section. The letters a, b, c, and d are assigned in a counter-clockwise direction, beginning in the northeast quarter of the section. For example, C3-65-15dada indicates the site is in the northeast quarter of the southeast quarter of the northeast quarter of the southeast quarter of Section 15, Township 3 South, Range 65 West.

SYSTEM OF NUMBERING WELLS & SAMPLING POINTS



30-a APPENDIX A

APPENDIX B

CHEMICAL ANALYSES OF WATER

(Results in milligrams per liter except as indicated)

Location (T-R-Sec.)	Owner	Use of water [a]	Well depth (Ft.)	Sample/Lab Date	Silica (SiO2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO3)	Bicarbonate (HCO3)	Sulfate (SO4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO3)	Dissolved solids (Calculated)	Hardness as CaCO3	Specific conductance (micromhos at 25°C)	pH	Remarks
Boulder County																						
01S-70W-24dda	Wagner Water Dist.	PS	300	6/11/80	9.1	10	.44	52	19	140	1.9	0	158	8.4	240	1.2	2.6	550	200	888	7.1	850 ft. gallery
1S-70W	Wagner Water Dist.	PS	300	6/11/80	9.0	10	.44	52	19	140	1.9	0	158	8.4	240	1.2	2.6	550	200	888	7.1	Composite of 4 well points
01S-70W-26dc	Base Line Water Dist.	PS	75	6/11/80	9.1	10	.44	52	19	140	1.9	0	158	8.4	240	1.2	2.6	550	200	888	7.1	Gallery
1S-69W-19dd	Sederlund	DS	20	10/1/80	--	--	--	--	--	8	1	0	30	3	11	.2	3.8	58	18	77	6.2	Gallery
Garfield County																						
5S-93W-34cad	C. Barnes	D	35	11/5/80	22	21	.44	44	44	9	1	0	213	6.1	93	.44	.44	350	260	559	8.3	
6S-92W-21dda	Bolton	D	450	11/1/80	--	--	--	--	--	22	10	2	2	0.4	198	--	--	300	6	450	9.4	
5S-88W-7ab	L. Smith	D	140	7/28/65	0.00	0.03	.21	13	231	140	3	0	3	0.1	375	180	566	0.3	7.3			
5-88	D. Black	D	13	7/28/65	0.01	0.0	80	93	330	380	16	0	0	0.1	540	592	310	6.0	7.6			
2Sxxx	E. Glover	I	125	7/28/65	0.13	0.0	100	130	343	1300	42	0	0.1	2900	280	1500	2120	0.2				
2Sxxx	E. Glover	I	110	7/28/65	0.01	0.0	13	50	280	47	9	0	32	0.1	970	236	1500	1360	7.5			
3S-93W-19bcb	Rosenbaum	I	42	6/9/65	0.20	.05	.03		125	1020	23	--	0.1	3013	180	1900	2450	0.2				
3xxx	O. Quasenbarth	I	90±	6/9/65	0.00	.05	.05		138	1080	23	--	0.1	3300	210	1970	3080	0.3				
8S-xxW-xxxx	Bolton [2]	PS	450	6/11/80	.01	1.2	.04	.04	28		10	2	0.2	866	198	600	1300	1.8				
Grand County																						
2S-76W-30bd	Sorbo Cattle Co. [2]	PS	21	7/28/65	--	800	.15	13	100	71	80	12	0.01	1300	260	768	1860	8.1				
2S-76W	Sorbo	PS	70	7/28/65	--	900	.11	17	12	984	92	13	0.01	1370	90	780	1891	8.2				
8S-82W-33bcb	Lott	S	80	6/11/80	--	122	.22	28	19	111	821	0.1	1.2	1300	410	1011	3660	2.3				

APPENDIX B

CHEMICAL ANALYSES OF WATER [a/] (continued)

Location (T-R-Sec)	Owner	Use of Water [b/]	Well Depth (ft.)	Sampling Date	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	ABS	Total Dissolved Solids	Total Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$	Conductance (Micromhos cm at 25°C)	pH	Remarks
Logan County (continued)																			
87-53-21ccc	V. Hessler	D	40	8/12/66	--	23	26	917	1800	212	410	4	0.07	2540	1480	165	3820	8.3	
25ccc	A. Fiehig	LI	25	8/12/66	--	161	86	152	332	759	49	0.1	0.02	1530	272	757	1950	8.2	
88-52-27dab	Sterling #1	PS	95	7/13/66		115	37	88	260	382	28	6	<0.05	857	213	438	1150	7.9	
27dcd	Sterling #3	PS	87	7/13/66		86	18	51	213	200	15	10	<0.05	531	175	287	758	8.3	
27ddb	Sterling #2	PS	110	7/13/66	--	130	34	90	255	402	29	8	<0.05	897	209	462	1150	8.3	
28bac	Sterling SJC	PS	66	7/13/66	--	286	74	362	388	1310	94	7	<0.05	2450	318	1017	2930	7.8	
28cdd	Sonnenberg #P-5	S	75	8/11/66	--	215	69	239	359	921	66	2	0.03	1790	294	820	2330	8.0	
32cda	Sterling	I	90	8/11/66	--	256	75	300	350	1180	84	8	0.02	2200	287	951	2650	7.9	
33abb	Sonnenberg #P-6	S	75	8/11/66	--	233	87	231	398	1010	79	1	0.01	1790	326	941	2550	7.9	
33aca	Sonnenberg #P-10	S	75	8/11/66	--	215	82	229	356	961	74	2	0.03	1880	292	873	2350	7.9	
33bda	Sonnenberg #P-7	S	75	8/11/66	--	253	76	237	374	1040	76	5	0.03	2020	307	944	2480	7.9	
33bcc	W. Thornburg	I	86	8/11/66	--	220	86	220	328	1030	71	2	0.02	1950	269	901	2440	7.8	
34abb	Sterling #4	PS	91	7/13/66	--	120	30	83	254	347	26	9	<0.05	801	208	425	1080	8.3	
34ab	Sterling #5	PS	114	7/13/66	--	86	18	48	227	185	14	15	<0.05	532	186	292	749	8.3	
34bdc	Sterling #6	PS	78	7/13/66	--	109	29	67	254	288	25	17	<0.05	718	208	392	998	8.1	
34cab	Sterling #7	PS	78	7/13/66	--	79	19	45	230	161	14	19	<0.05	499	189	277	720	8.1	
34cbc	Sterling #8	PS	65	7/13/66	--	57	13	14	226	40	3	28	<0.05	287	185	195	446	8.1	
34ccb	Sterling #9	PS	71	7/13/66	--	58	10	10	189	37	3	27	<0.05	271	155	184	408	7.8	
34ccd	Sterling #10	PS	80	7/13/66	--	55	8	9	173	30	2	24	<0.05	259	142	170	427	8.1	
88-53-25bda	Sterling #3	PS	82	7/13/66	--	189	54	117	297	624	57	16	<0.05	1320	244	694	1680	7.9	
25bda	Sterling #2	PS	80	7/13/66	--	193	54	117	305	626	59	16	<0.05	1320	250	704	1680	7.8	
25bda	Sterling #1	PS	80	7/13/66	--	185	51	117	286	626	56	15	<0.05	1300	235	675	1630	7.7	
89-51-16bda	Iliff	PS	70	7/14/66	--	281	132	764	524	2210	170	9	0.05	4010	430	1245	4620	7.8	
810-49-11cba	Crook	PS	55	7/15/66	--	257	53	223	311	919	117	9	<0.05	1840	255	862	2220	7.5	
Morgan County																			
82-56-27abb	Hunt Oil Co.	Ind	74	4/13/67	--	96	--	152	253	456	21	6	0.03	1021	253	386	1375	7.8	
83-56-26bbc	Brush #52	PS	114	7/28/66	--	25	6	9	110	13	2	2	0.01	127	90	87	206	8.4	
27abb	Brush #41	PS	95	7/28/66	--	23	5	8	102	15	2	1	0.01	118	84	79	196	8.2	
27add	Brush #55	PS	170	7/28/66	--	22	4	9	93	15	1	4	0.02	112	76	73	186	8.2	
83-57-5bda	Fort Morgan	PS	--	7/27/66	<0.02	180	130	89	336	778	54	16	0.01	1550	276	984	1830	8.0	Mn= <0.01
6adc	Fort Morgan	PS	189	7/27/66	0.02	258	53	107	262	785	51	21	0.02	1510	215	866	1840	7.8	Mn= 0.02
6add	Fort Morgan	PS	211	7/27/66	<0.02	288	61	106	320	813	55	21	<0.01	1620	262	970	2000	8.0	Mn= 0.08
6bdd	Fort Morgan	PS	175	7/27/66	0.02	265	43	107	304	773	51	25	0.01	1520	249	830	1820	8.0	Mn= 0.02

APPENDIX B

CHEMICAL ANALYSES OF WATER [a/] (continued)

Location (T-R-Sec)	Owner	Use of Water [b/]	Well Depth (ft.)	Sampling Date	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	ABS	Total Dissolved Solids	Total Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$	Conductance (Micromhos/cm at 25°C)	pH	Remarks
									Morgan County (continued)										
B3-57-6cdc	Fort Morgan	PS	179	7/27/66	0.02	272	61	100	288	803	52	22	0.0	1550	235	931	1840	7.8	Mn= <0.01
6dcb	Fort Morgan	PS	250	7/27/66	<0.02	273	57	96	260	821	53	23	0.01	1560	213	918	1840	7.7	Mn= 0.02
8bbd	Fort Morgan	PS	175	7/27/66	<0.02	261	53	109	279	765	50	25	<0.01	1510	229	870	1820	8.0	Mn= 0.9
B3-58-1adb	Fort Morgan	PS	253	7/27/66	<0.02	253	53	100	300	732	51	36	<0.01	1480	246	807	1820	8.1	Mn= 0.23
1daa	Fort Morgan	PS	217	7/27/66	<0.02	275	51	132	368	859	53	35	0.02	1570	302	896	1790	8.0	Mn= 0.02
1ddb	Fort Morgan	PS	230	7/27/66	0.1	329	68	117	252	722	48	27	<0.01	1390	198	795	1760	8.0	Mn= 0.02
B4-55-10cac	Hillrose Service Station	D	90	8/25/66	--	168	32	92	296	295	35	8	0.0	1070	262	602	1390	8.1	
B4-56-23cdc	Hansen Bros.	S	35	8/25/66	--	183	62	156	344	673	61	1	0.0	1420	282	714	1820	7.8	
27ccb	J. Fries	I	100	4/13/67	--	257	--	208	346	968	66	3	0.09	1969	346	953	2390	7.4	NH_3-N=0.8, NO_2-N<0.1, Tot.N=0.84
33abb	G. Marble	I	120	4/14/67	--	242	--	192	367	893	63	3	0.1	1879	347	922	2270	7.4	NH_3-N=0.8, NO_2-N<0.1, Tot.N=0.96
34bcd	S. Weisbart	S	100	4/14/67	--	229	--	136	349	768	56	7	0.09	1575	349	814	1960	7.4	NH_3-N=0.09, NO_2-N<0.1, Tot.N=0.05
34ccd	Richards	I	87	4/14/67	--	193	--	124	283	644	52	8	0.07	1382	283	715	1783	7.4	NH_3-N=0.6, NO_2-N<0.1, Tot.N=0.74
B4-58-35aca	Loglane Village	PS	77	7/27/66	<0.02	166	46	102	256	319	41	16	<0.01	1130	210	602	1470	8.2	Mn= 0.19
36caa	Fort Morgan	PS	93	7/27/66	<0.02	185	33	95	220	353	34	21	0	1070	180	597	1470	8.1	Mn= 1.25
B4-60-21add	G. Bernhardt	D	65	5/15/67	--	182	--	172	239	367	31	92	0.4	1065	239	568	1482	7.8	
									Sedgwick County										
B11-46-18abc	Sedgwick	PS	42	7/26/66	--	331	56	210	326	--	95	27	0.05	--	267	1060	2400	8.1	
19daa	Sedgwick	PS	21	7/26/66	--	61	10	16	186	38	18	31	0.02	311	153	195	480	8.2	Composite sample of 3 wells
B11-47-12dcd	Anna Jenig	D	--	7/26/66	--	285	36	197	266	1010	89	11	0.0	1960	217	963	2360	7.8	
B12-44-28cad	Julesburg	Ind	26	7/26/66	--	212	43	128	314	631	62	23	0.0	1380	257	710	1750	7.9	
29aad	Julesburg	PS	108	7/26/66	--	238	42	162	284	730	68	35	0.02	1530	233	766	1810	8.2	
29adb	Julesburg	PS	--	7/26/66	--	159	32	120	244	503	45	22	0.01	1090	200	527	1410	8.3	
B12-45-26aab	Julesburg	PS	84	7/26/66	--	107	20	71	209	284	30	15	0.02	889	171	349	930	8.2	
26abd	Julesburg	PS	84	7/26/66	--	107	20	77	208	292	30	15	0.01	694	171	350	926	8.2	
26bda	Julesburg	PS	80	7/26/66	--	159	29	102	214	567	53	13	0.01	979	175	593	1300	8.3	
29add	Ovid	PS	100	7/26/66	--	65	13	31	226	76	13	13	0.01	366	185	212	554	8.3	Composite of 4 wells

APPENDIX B

CHEMICAL ANALYSES OF WATER [a/] (continued)

Location (T-R-Sec)	Owner	Use of Water [b/]	Well Depth (ft.)	Sampling Date	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	ABS	Total Dissolved Solids	Total Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$	Conductance (Micromhos/cm at 25°C)	pH	Remarks
									Weld County										
B1-64-18ccc	J. Foos	I	60	7/15/65	0.08	400	109	220	366	1310	135	43	0.2	2770	300	1450	3150	7.3	
B1-65-11aaa	Hudson	PS	47	6/14/65	1.38	241	53	108	605	590	187	26	0.1	1770	496	822	2560	7.6	
12dcc	E. Bernhardt	I	61	7/15/65	0.12	151	42	122	433	272	104	34	0.1	1040	355	550	1580	7.3	
30dcb	G. Henkel	I	54	7/15/65	0.19	114	60	192	436	318	129	26	0.2	1110	358	530	1700	7.6	
B1-66- 6aaa	Fort Lupton #3	PS	55	5/12/65	--	--	--	--	360	272	120	56	0.4	--	295	--	1520	7.4	
6abd	Fort Lupton #4	PS	50	5/12/65	--	--	--	--	339	282	128	42	0.4	--	278	--	1540	7.6	
6daa	Fort Lupton #1	PS	57	5/12/65	0.37	123	51	148	372	322	144	47	0.4	1110	305	518	1710	7.4	
6daa	Fort Lupton #2	PS	55	5/12/65	--	--	--	--	374	322	150	39	0.3	--	307	--	1710	7.4	
19dcc	F. Doughty	S	18	10/18/65	--	128	--	--	262	244	147	78	0.3	1040	215	475	1430	7.3	
19dcd	Beautiful View Trailer Park	D	52	6/30/65	0.16	125	33	126	283	242	150	86	0.5	853	232	448	1390	7.1	
29ccc	W.E. Dittmer	I, D	36	6/30/65	0.14	171	17	128	349	270	156	79	0.2	930	286	286	1560	7.1	
30abc	G.Mancini Feedlot	S	40	6/30/65	0.16	131	27	116	341	182	150	51	0.2	1010	280	440	1410	7.1	
31cdc	Sylmar Manor Mobil Home Park	D	100	7/12/65	0.0	170	45	172	371	369	164	60	0.3	1260	304	610	1790	7.4	
31ddc	M. Tashiro	I	36	7/15/65	1.02	139	56	192	380	364	164	27	0.2	1290	312	580	1760	7.3	
36dca	Spaceous Living Inc.Mobil Home Sites	D	97	6/14/65	0.08	85	42	78	346	178	97	31	0.4	763	284	387	1200	7.6	
B1-67-3aaa	J.Berger	D, S	25	7/12/65	0.04	160	91	--	419	620	156	14	0.3	1840	344	775	2340	7.5	
B2-62-6bcc	Roggen School	D	80	6/14/65	0.3	37	--	--	133	87	11	0	0	288	109	128	484	7.4	
B2-65-13bcd	R. Harkis	I	51	7/15/65	0.19	198	79	172	313	666	106	58	0.1	1560	257	720	2080	7.5	
16bcc	H. Thompson	I	83	7/15/65	0.22	223	108	384	318	1050	201	42	0.2	2340	261	1000	3060	7.6	
35ddd	Hudson	PS	60	6/14/65	0.22	229	48	176	483	503	148	35	--	1560	396	770	2240	7.7	
B2-66-6dcd	A. Miller	I	--	7/12/65	1.15	58	35	110	236	192	76	37	0.2	687	194	293	995	6.9	
B3-64-17cdd	Two E Ranch	I	65	7/19/65	0.10	341	90	375	424	--	175	31	0.1	2960	348	1200	3640	7.8	
B3-65-22ccd	J. Wardell	I	79	7/19/65	0.12	240	79	300	300	1010	201	33	0.1	2250	246	924	2930	7.5	
B3-66- 7cdd	Eilers Corner Trailer Village	D	52	7/12/65	0.04	88	60	112	350	278	97	33	0.3	939	287	465	1330	7.3	
19bdb	Platteville #1	PS	5?	5/12/65	0.01	107	63	108	347	250	114	27	0.2	887	285	432	1400	7.2	
				6/30/65	--	--	--	--	--	--	--	--	--	--	--	--	1320	7.2	Oil=1.4 mg/l
				7/7/65	--	--	--	--	--	--	84	--	--	--	--	--	--	--	Oil=5.1 mg/l
				1/6/66	--	--	--	--		242	119	16	< 0.1	915	278	--	1190	6.9	Oil=33.0 mg/l
19cab	Platteville #2	PS	57	5/12/65	--	--	--	--	347	242	111	27	0.3	--	285	--	1410	7.4	

APPENDIX B

CHEMICAL ANALYSES OF WATER [1/] (continued)

Location (T-R-Sec)	Owner	Use of Water [2/]	Well Depth (ft.)	Sampling Date	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO3)	Sulfate (SO4)	Chloride (Cl)	Nitrate (NO3)	ABS	Total Dissolved Solids	Total Alkalinity as CaCO3	Total Hardness as CaCO3	Conductance (Micromhos at 25°C)	pH	Remarks
									Weld County (continued)										
B3-67-13add	H.Cymanski	I	54	7/12/65	0.04	90	50	112	324	252	102	31	0.2	878	266	430	1270	7.2	
B4-61-19dab	L. Gallagher	D	115	1/6/66	--	137	--	--	312	477	49	8	< 0.1	1070	256	552	1400	7.4	
B4-65-8aba	LaSalle #4	PS	66	5/13/65	0	135	71	120	380	386	86	53	0.2	1090	312	590	1580	7.4	
6daa	G. Goodner	I	83	7/21/65	0.05	158	60	138	380	401	110	49	0	1300	312	660	1690	7.0	
11cdc	G. Whitman	I	72	7/19/65	0.3	155	56	224	397	614	148	35	0.1	1620	326	728	2280	6.8	
B4-66-14bcc	E. MacArthur	I	69	7/12/65	0.04	120	44	108	316	291	105	64	0.3	1010	259	480	1400	7.2	
22dcc	Southgate Mobil Home Sites	D	70	7/12/65	0.04	116	66	124	364	332	105	44	0.2	1070	299	560	1480	7.3	
27ccc	H. Nelson	I	83	7/6/65	0.25	113	36	98	316	280	106	68	0.2	979	274	428	1510	7.7	
28adc	Gilcrest #1	PS	98	5/13/65	0.14	127	56	124	257	291	105	102	0.2	1050	293	546	1490	7.4	
28adc	Gilcrest #2	PS	98	5/13/65	--	--	--	--	223	316	108	102	0.2	--	265	--	1470	7.6	
31aca	Farr Farms	I	60	7/6/65	0.1	101	42	40	333	230	103	37	0.1	903	273	426	1430	7.3	
31dcc	Farr Farms	I	83	7/6/65	--	--	--	--	--	306	100	56	0.3	--	--	--	1520	7.0	
B4-67-12cdd	E.Sappington	I	33	7/12/65	0	152	83	92	360	542	20	54	0.2	1260	239	720	1520	7.4	
B5-63-34cca	T. Helus	D	20	1/6/66	--	188	--	--	397	830	88	12	< 0.1	1861	325	873	2050	7.2	
B5-64-3ccc	R. Johnson	I	70	7/21/65	0.3	330	111	226	455	1400	61	13	0	2730	373	1280	3130	7.1	
21bca	Kersey #1	PS	39	7/1/65	0.5	189	86	175	375	634	75	32	0.1	1520	307	824	2250	7.2	
21bbc	Kersey #2	PS	67	7/1/65	0.25	167	73	160	381	720	75	30	0.1	1550	288	724	2050	7.4	
22dab	W. Ledford	I	67	7/19/65	0.17	171	96	148	350	755	65	60	0.1	1700	287	822	2210	7.6	
25ddd	Paul Yago	S	60	7/19/65	0.05	360	90	238	419	1350	106	21	0.1	2730	344	1266	3200	7.3	
B5-65-25bbb	H. Johnson	D	--	7/19/65	0.12	196	191	300	687	1030	108	20	0.1	2270	383	898	2850	8.0	
31dbd	LaSalle #3	PS	83	5/13/65	--	--	--	--	277	354	85	49	0.1	--	309	--	1440	7.6	
B6-63-18cdd	J. Cantrell	S	50	12/13/65	--	166	--	--	583	1160	59	16	0.1	2307	380	685	2300	7.5	
B6-65-18abb	M. B. Walek	I	80	8/17/65	--	308	90	--	525	862	26	36	0.1	1990	348	1140	2360	7.2	
29bdc	L. Adams	I	81	7/20/65	0.15	295	99	100	372	956	30	40	0	2050	305	1150	2280	7.6	
30aaa	G. Hood	I	65	7/20/65	0.14	352	117	140	390	1260	35	60	0.1	2650	320	1360	2680	7.2	
30bbd	F. Downs	I	65	7/20/65	0.07	202	118	113	355	890	23	28	0.1	1780	291	990	2100	7.4	
30cdd	Monfort Feed-lots	S, I	65	7/20/65	0.68	290	133	145	477	1100	32	33	0.1	2385	391	1270	2610	7.3	
30dcd	J. Sargent	S	40	7/20/65	3.73	356	129	160	442	1250	38	44	0.0	2650	363	1390	2863	7.5	
B6-66-21baa	C. Leffler	I	31	7/22/65	0.1	138	137	124	377	731	29	17	0	1900	309	910	2290	7.6	
24aab	H. Nelson	I	21	7/20/65	2.78	218	186	164	429	1450	24	25	0.1	2660	106	1300	2750	6.2	
24ada	R. Peterson	I	53	7/20/65	0.65	340	265	240	380	2000	31	32	0.1	3370	312	1960	3680	7.1	
25ddb	J. Heckman	I	31	7/20/65	0.76	280	180	165	390	1420	35	33	0.1	2880	320	1440	2860	7.2	
28cdd	R. Anderson	S	40	7/22/65	0.08	171	126	112	450	893	67	37	0	1770	369	963	2190	7.4	

APPENDIX B

CHEMICAL ANALYSES OF WATER [a/] (continued)

Location (T-R-Sec)	Owner	Use of Water [b/]	Well Depth (ft.)	Sampling Date	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	ABS	Total Dissolved Solids	Total Alkalinity as $CaCO_3$	Total Hardness as $CaCO_3$	Conductance (Micromhos at 25°C)	pH	Remarks
									Weld County (continued)										
B6-67-18bdb	H. Fagerberg	I	27	7/22/65	0.11	210	85	88	390	703	24	36	0	1620	320	875	1950	7.4	
26aba	H. Schaefer	I	33	7/22/65	0.04	257	165	160	447	1260	39	25	0	2560	367	1320	2860	7.6	
B7-65-15bba	C. Hennick	I	29	8/17/65	0.05	212	45	--	405	900	26	52	0.1	1280	332	715	1690	7.2	
31cba	Eaton #1	PS	--	5/17/65	0.12	98	87	78	412	352	26	33	0.1	1060	338	602	1320	7.4	
B7-66-6bba	P.Balamonte	S	15	10/20/65	--	--	--	--	295	524	57	21	0.1	1200	242	--	1570	7.4	
3bdab	Eaton #2	PS	--	5/17/65	--	--	--	--	413	360	19	28	0.1	--	339	--	1280	7.4	
B7-67-34daa	C. Felte	N	24	8/2/65	1.14	382	383	116	375	2130	172	1	0.2	4066	308	2530	4180	7.4	
34ddd	C. Felte	LI	26	7/26/65	--	504	--	--	573	3010	240	64	--	6570	470	3370	6670	7.9	
34ddd	C. Felte	LI	25	7/26/65	0.24	503	510	500	583	3640	216	46	0.2	6365	478	3350	6540	7.2	
35acd	J. Brown	I	25	8/2/65	--	84	--	--	350	388	10	25	--	1000	287	600	1580	7.6	
35bbb	Brownell	N	19	10/28/65	--	420	--	--	493	3320	145	18	0.3	6020	404	3540	5800	7.6	
B8-66-22dab	M. Thomas	I	38	7/6/65	--	58	--	--	--	171	22	--	--	--	--	--	230	7.7	
26bbc	Pierce #1	PS	40	5/17/65	--	--	--	--	279	71	24	28	0.1	--	229	--	683	7.8	
26bca	Pierce #2	PS	37	5/17/65	0.02	71	24	33	277	69	24	32	0.1	472	227	276	682	8.0	
26cbb	D. Woods	I	41	7/6/65	--	103	--	--	--	96	32	--	0.1	--	--	--	954	7.6	
27aaa	Pierce School Dist.	LI	41	7/6/65	0	86	22	94	318	70	20	32	0.1	508	261	306	815	7.8	
27aac	L. Cogswell	LI	30	7/6/65	--	--	--	--	--	117	160	--	--	--	--	--	1480	7.6	
27abd	Leslie	D	34	7/6/65	0.08	142	33	--	278	144	239	66	0.2	1040	228	490	1660	7.4	
27ada	Pierce #3	PS	41	5/17/65	0.02	94	19	53	339	100	25	25	0.1	561	278	310	816	8.0	
27add	C. Peterson	I	42	7/6/65	--	91	--	--	--	89	42	--	0.2	--	--	--	999	7.6	
27add	C. Peterson	I	40	7/6/65	--	115	--	--	--	110	58	--	0.1	--	--	--	1060	7.6	
27daa	M. Geib	I	24	7/6/65	--	70	--	--	--	106	48	--	--	--	--	--	1005	7.6	
28ddd	P. Kerr	D	24	8/17/65	0.13	140	33	--	407	95	9	21	0.1	842	334	485	1250	7.2	
33aaa	F. Kerr	D	42	10/20/65	--	--	--	--	407	371	91	42	0.3	1240	334	--	1660	7.6	
31ccc	N. Brown	S	18	10/26/65	--	106	--	--	316	302	71	1	0.1	963	259	474	1160	7.3	
B9-66-33cac	Nunn #1	PS	39	5/13/65	0	82	24	20	212	59	10	160	0.2	490	174	304	683	7.7	
33cbd	Nunn #2	PS	55	5/13/65	--	--	--	--	224	43	12	98	0.2	--	184	--	588	7.6	
B12-62-34baa	Bowl Cafe	D	--	12/13/65	--	44	--	--	181	20	8	16	0.2	254	148	150	298	7.6	

a/ South Platte River Basin Project Laboratory, Denver, Colorado and Colorado River Basin Project Laboratory, Salt Lake City, Utah
b/ D - Domestic; I - Irrigation; LI - Lawn Irrigation; N - Not used; PS - Public Supply; S - Stock.

APPENDIX C

CHEMICAL ANALYSES OF WATER ASSOCIATED WITH PETROLEUM-BEARING FORMATIONS
(Results in Milligrams per Liter)

County	Field	Operator	Well or Lease Name	General Location (T-R-Sec.)	Type of Sample	Date of Analysis	Chlorides (Cl)	Sulfate (SO_4)	Bicarbonate (HCO_3)	Calcium (Ca)	Sodium (Na)	pH	Total Dissolved Solids
				DAKOTA "D" SANDSTONE									
Logan	Cedar Creek	British-American	Middlestadt Lease	B9-54-13	P	9/22/58	5675	16	1891	20	4367	8.0	11,974
	Cliff	British-American	#A-1 Casement	B12-54-32	P	9/22/58	3688	116	2166	12	3243	7.9	9,229
	Cliff	Sinclair O. & G. Co.	L. Hiscock Lease	B12-54-32	P	-	4184	50	1605	32	3316	-	9,195
	Dale	Shell Oil Co.	#2 Haywood "A"	B8-53-23	DST	10/10/52	4780	68	2140	34	3880	7.5	-
	Elm Grove	Pan American	#7 State "K"	B6-53-16	DST	8/20/59	2759	856	1014	19	2660	8.9	7,255
	Garnet	British-American	#1 Koester "C"	B10-57-30	DST	3/3/59	4255	56	1867	22	3089	7.4	9,588
	Gravlin-NW	British-American	#11 Unit	B8-56-1	P	11/13/61	5200	75	1280	18	3900	7.7	± 12,500
	Gravlin-NW	British-American	Monroe "C" Lease	B8-56-1	P	6/18/61	5503	50	2001	12	4322	8.0	11,897
	Gravlin-NW	British-American	#36 Unit	B8-56-1	P	11/13/61	5270	85	1370	21	3960	7.8	12,400
	Padroni-West	Sinclair O. & G. Co.	Arthur Sindt	B9-52-7	-	-	4184	-	1415	13	3136	-	8,864
Morgan	Burr	H. L. Hunt	#1b Huey	B2-56-29	-	10/10/63	4000	-	-	-	-	8.3	-
	Fort Morgan	Natural Gas Producers	#1 Unit	B3-57-19	P	10/5/61	6150	133	1290	75	3620	7.4	-
	Fort Morgan	Natural Gas Producers	#7 Unit	B3-57-19	P	9/21/61	6240	95	1230	53	3480	6.8	-
	Fort Morgan	Natural Gas Producers	#9 Unit	B3-57-19	P	9/27/61	5950	80	1235	42	4290	6.9	-
	Park	Phillips Petrol. Co.	#A-1 Hawses	B1-58-19	DST	5/9/62	4820	40	939	62	3381	7.7	8,902
	Rake	Colorado O. & G.	#1 Ruyle	B4-60-23	P	10/30/63	5726	124	2998	1026	-	5.1	-
	Rake	Colorado O. & G.	#1 Stroh	B4-60-26	P	10/28/63	6960	105	1132	91	-	7.3	-
	Rake	Colorado O. & G.	#1 Alles	B4-60-26	P	10/28/63	6996	92	1167	55	-	7.1	-
	Sand River	Skelly Oil Co.	Max Peterson Lease	B1-58-27	P	7/16/63	3300	24	1639	16	-	7.5	6,719
Sedgwick	Chappel	Graham-Michaelis Co.	#1 Plessinger	B11-44-2	-	-	5519	< 10	2294	11	-	-	-
	Chappel	Graham et. al.	State	B12-44-36	-	-	5090	< 10	2181	12	-	-	-
Weld	Jasper	Gulf Oil Corp.	#1 Roach	B12-57-28	S	3/30/59	4160	-	1110	39	4036	8.3	8,469
				DAKOTA "J" SANDSTONE									
Logan	Armstrong	British-American	#E-1 Roper	B11-53-23	DST	10/10/58	4166	606	2472	32	3852	7.4	11,160
	Atwood	Trigood Oil Co.	#J-18 Pomeroy	B7-53-29	P	3/3/53	1200	94	2960	-	2058	8.2	5,041
	Beall Creek	P. Doheny	#3 Middlestadt	B10-53-23	DST	10/23/57	1758	700	762	25	1481	8.3	4,757
	Cliff	British-American	#5 Griffith	B12-54-32	DST	1/6/59	833	630	1366	10	1415	8.6	4,386
	Cliff	Sinclair O. & G. Co.	H. S. Ayres Lease	B12-54-28	P	-	684	160	964	8	956	-	2,955
	Dale	Shell Oil Co.	#2 Haywood "A"	B8-53-23	DST	10/11/52	1140	57	1700	28	2180	8.0	-
	Goat Hill	British-American	Reiner "B" Lease	B11-53-22	P	9/22/58	3245	686	2483	13	3228	7.8	9,472
	Lewis Creek	British-American	Union Pacific Lease	B11-53-12	P	2/25/60	3103	561	2172	9	3073	8.0	8,936
	Little Hoot	British-American	#1 Fogale	B11-54-35	DST	2/17/58	2152	600	2855	18	2624	7.5	8,359
	Merino	Trigood Oil Co.	#J-17	B6-54-21	-	11/17/52	1420	89	2475	Trace	1989	8.5	5,262
	Mount Hope	U. S.Smelting,R.,M.Co.	#1 Hume	B9-53-30	P	10/17/53	2650	320	2434	0	2840	8.3	-

APPENDIX C

CHEMICAL ANALYSES OF WATER ASSOCIATED WITH PETROLEUM-BEARING FORMATIONS
(Continued)

County	Field	Operator	Well or Lease Name	General Location (T-R-Sec.)	Type of a/ Sample	Date of Analysis	Chloride (Cl)	Sulfate (SO_4)	Bicarbonate (HCO_3)	Calcium (Ca)	Sodium (Na)	pH	Total Dissolved Solids
				DAKOTA "J" SANDSTONE (Continued)									
Logan	Padroni-West	Sinclair O. & G. Co.	W. F. Dickenson Lease	B9-52-6	-	-	1897	299	1943	14	2030	-	6,324
	Pawnee Creek	Skelly Oil Co.	D. M. Kerr	B8-51-35	P	7/7/53	696	-	-	-	-	-	-
	Spring Creek	Flagg et. al.	#2 Niclaus	B9-53-10	P	10/28/63	1222	210	2830	16	19.0	8.0	6,215
	Springdale-South	Shell Oil Co.	Dollerschell Lease	B8-53-28	P	1/14/65	800	10	2623	8	1634	8.4	5,246
	Springdale-South	Shell Oil Co.	Rice Lease	B8-53-28	P	1/14/65	780	8	2647	8	1620	8.4	5,222
	Yenter	Shell Oil Co.	Edens Lease	B8-54-2	P	6/24/53	2260	380	2650	8	2700	9.5	8,090
	Yenter	British-American	Yenter A-2	B8-54-3	P	10/9/59	1861	197	3117	7	2591	8.6	7,470
	Yenter	British-American	Yenter A-1	B8-54-3	P	9/22/58	1394	214	3294	8	2234	7.9	7,154
Morgan	Adena	Pure Oil Co.	"J" Unit Wells	B1-57-6	P	8/19/63	2480	325	-	14	2392	8.2	6,872
	Adena-South	Wayne McDanial	#1 State	B1-58-35	P	5/25/63	5530	460	1364	23	-	7.9	-
	Bijou-West	British-American	#1 Bender	B4-60-12	DST	2/6/58	5319	358	1963	72	4194	7.1	11,938
Washington	-	Ohio Oil Co.	#1 Burns	B2-52-34	DST	5/26/61	653	6	2477	24	1330	8.2	5,279
Weld	Battle Canyon	Midwest Oil Co.	#1 Uhl	B11-56-21	DST	1/23/53	3000	700	1540	32	2800	7.7	8,100
	Battle Canyon	Shell Oil Co.	State "C"	B11-56-16	DST	12/14/53	1614	450	1690	41	1667	8.0	5,560
		Some Oil Co.	#1 State	B7-57-18	P	1/16/57	3976	68	653	201	2396	7.0	-
				DAKOTA "D" SANDSTONE									
Logan	Padroni-West	Sinclair O. & G. Co.	#1 Parke	B9-52-6	-	3/29/57	1810	231	2270	2	2135	8.2	-
	Padroni-West	Sinclair O. & G. Co.	Arthur Sindt	B9-52-7	-	-	2092	379	1367	18	1975	-	5,975
				"SUSSEX" SANDSTONE									
Weld	New Windsor	California Co.	#1 Canal	B7-67-34	P	10/1/57	6900	145	930	24	3643	9.2	10,228
	New Windsor	California Co.	#1 Denney	B7-67-27	P	10/23/57	4760	33	1070	41	3506	8.3	9,696
	New Windsor	California Co.	#2 Denney	B7-67-27	P	10/23/57	4580	-	975	41	3236	8.1	9,668
				LYONS SANDSTONE									
Weld	New Windsor	California Co.	#2 Brunner	B7-67-26	P	12/2/57	3400	14798	1195	80	9503	8.0	28,128
	New Windsor	California Co.	#1 P. Urlich	B7-67-26	DST	11/29/57	1760	13587	1255	189	7731	7.4	23,706
	New Windsor	Ashland O. & R. Co.	#1 Rumerhall	B7-67-26	P	12/28/62	2560	6830	795	195	4900	7.2	-
	Pierce	California Co.	#1 Batman	B8-66-26	DST	9/4/57	35000	6123	620	1140	23832	5.0	66,800
	Pierce	California Co.	#1 Geib	B8-66-28	P	12/2/57	26000	8279	390	159	20474	8.0	54,910
	Pierce	California Co.	#1 Kennedy	B8-66-27	P	12/2/57	19000	6267	1158	127	15385	7.2	38,200
	Pierce	California Co.	#1 King	B8-66-22	P	12/2/57	49000	906.7	315	310	35624	7.8	96,920
	Pierce	California Co.	#2 Priddy	B8-66-23	P	12/2/57	30000	9617	1170	142	23932	7.6	64,230
	Pierce	California Co.	#3 Priddy	B8-66-23	P	12/2/57	26000	8098	730	156	20489	7.2	55,210
	Pierce	California Co.	#1 Fee	B8-66-26	P	12/2/57	56000	5959	500	283	38138	7.2	95,230
	Pierce	California Co.	#1 C.P.R.R.-Fee	B8-66-15	P	12/2/57	35000	6456	560	221	24442	8.0	65,720
	Pierce	California Co.	#1 Walker	B8-66-28	P	12/13/57	25000	6481	770	472	18180	6.8	51,680

a/ DST - Drill Stem Test; P - Produced Water; S - Swabbed

APPENDIX D

REPORTED QUANTITIES OF WATER PRODUCED AND INJECTED IN OIL AND GAS FIELDS IN 1966

County	Field Name	General Location (T-R-Sec)	Geologic Formation Exposed at a/ Land Surface	Associated Water Produced b/ (Barrels)	Injected Water c/ (Barrels)
Larimer	Clarks Lake	B9-68-15	Kp	33,197	288,600
	Fort Collins	B8-68-30	Kp	129,672	-
	Loveland	B5-68-30	Kp	15,366	-
	Wellington	B10-68-31	Qv, Kp	908,152	-
Logan	Amber	B11-54-25	Tw	143,751	-
	Armstrong	B11-53-26	To	70,514	-
	Atwood	B7-53-20	Qd, Qv	99,359	-
	Atwood-East	B7-53-25	Qd, Qv	879,313	1,296,638
	Beall Creek	B10-53-23	Tw	305,319	81,983
	Big Sandy	B8-55-2	Kp	108,000	-
	Bonanza	B10-53-15	Tw	242,400	-
	Camino	B6-52-9	Qd	196	-
	Cayuse	B9-52-30	Tw	3,979	-
	Cedar Creek	B9-54-12	Tw	41,381	-
	Cedar Creek-North	B9-54-1	Tw	45,736	-
	Chess	B9-53-13	Qv, Kp	1,778	-
	Cliff	B12-54-32	To, Tw	223,719	-
	Cottonwood-South	B9-55-24	Tw	41,017	-
	Dale-North	B8-53-14	Qv	9,050	-
	Darby Creek	B10-53-17	Tw, Kp	128,618	-
	Divide	B8-53-9	Qv, Kp	912,448	1,094,981
	Dune Ridge	B7-52-32	Qd	428,754	388,566
	Elm Grove	B6-53-15	Qv	188,019	-
	Falcon	B12-52-34	To	180,544	-
	Ford	B9-52-26	Qv	32,281	-
	Frasco	B7-55-4	Tw	494,708	-
	Garnet	B10-53-30	Kp	18,210	-
	Goat Hill	B11-53-22	To	51,372	-
	Graylin-NW	B8-53-7	Kp	2,680,521	2,965,568
	Horse Tail	B10-54-35	Kp	27,154	-
	Johnson Hill	B8-54-18	Tw	74,981	-
	Key	B8-54-25	Kp	34,635	-
	Lewis Creek	B11-53-12	To	1,316,930	1,946,348
	Liberty	B8-54-5	Tw	143,702	715,877
	Liberty-West	B8-54-6	Tw	118,514	-
	Little Hoot	B10-54-11	Tw, Kp	60,670	-
	Lodge	B8-54-14	Kp	35,565	-
	Logan	B8-54-22	Kp	21,600	-
	Logan-North	B8-54-15	Kp	109,100	-
	Luft	B8-53-17	Qv, Kp	250,308	206,366
	Merino	B6-54-19	Qd	573,530	90,000

APPENDIX D
(Continued)

County	Field Name	General Location (T-R-Sec)	Geologic Formation Exposed at Land Surface [a]	Associated Water Produced (Barrels) [b]	Injected Water (Barrels) [c]
Logan	Minto	B8-52-6	Qv, Tw	378,812	273,395
	Minto-North	B9-53-25	Tw	120	-
	Mount Hope	B9-53-30	Tw, Kp	1,025,863	4,049,896
	Mount Hope-East	B9-53-29	Tw	245,512	-
	Nabar	B11-54-32	Kp	2,220	-
	Noria	B11-53-33	To	2,215	-
	North Shore	B10-53-28	Kp	9,177	-
	Padroni	B9-52-20	Qv	488	-
	Padroni-West	B9-52-6	Tw, Kp	1,247,170	144,290
	Pawnee Creek	B7-54-3	Qv, Kp	344,876	-
	Peavy	B12-55-19	To	20,777	-
	Pebble	B12-52-21	To	107,825	-
	Peetz-NW	B12-52-29	To	3,183	-
	Peetz-West	B11-52-6	To	150,210	-
	Prairie View	B10-53-29	Kp	995	-
	Prewitt	B6-54-36	Qv	8,643	-
	Raymer Creek	B8-55-15	Tw	5,741	-
	Saber	B10-55-7	Tw, Kf	88,207	-
	Sandy Hill	B7-52-20	Qd	28,724	-
	Scarp	B11-54-8	Tw	59,526	-
	Shield	B8-53-31	Qv	493,608	-
	Shoreline	B9-53-9	Tw, p	46,709	-
	Springdale-South	B8-53-28	Qv	122,778	-
	Stoney Buttes	B11-55-24	Kp	25,468	-
	Twin Mills	B7-51-18	Qd	19,048	-
	Vista	B11-54-9	Tw	15,723	-
	Walker	B9-53-20	Tw	264,983	-
	Warrior	B9-54-23	Tw	91,567	-
	West Plains	B10-54-31	Kp	14,199	-
	Winston	B10-52-6	Tw	-	156,640
	Yenter	B8-54-3	Tw, Kp	699,112	821,250
Morgan	Adena	B1-57-20	Qd,Qv,Kp	5,419,568	5,174,149
	Adena-South	B1-58-35	Kp	20,351	-
	Allen	B2-56-9	Qd	65,235	-
	Ashley	B2-59-1	Qv	3,095	-
	Bijou	B4-59-8	Qd, Qv	183,226	2,207,948
	Bijou-West	B4-60-12	Qv	3,366	-
	Boxer	B2-58-32	Qd, Qv	21,651	-
	Burr	B2-56-29	Qd	146,648	-
	Forge	B2-57-7	Qv	28,100	-
	Fort Morgan	B3-57-19	Qv	176,416	176,416
	Gary-North	B2-56-27	Qd	95,042	101,271

APPENDIX D
(Continued)

County	Field Name	General Location (T-R-Sec)	Geologic Formation Exposed at Land Surface [a]	Associated Water Produced (Barrels) [b]	Injected Water (Barrels) [c]
Morgan	Gringo	B1-55-30	Qv	4,264	-
	Hunter	B1-55-31	Qv	30,400	-
	Jackpot	B6-59-1	K1, Kf	119,402	290,717
	Jackson	B5-60-25	Qv	10,300	-
	Jubilee	B2-55-12	Qd	10,950	-
	Lamb	B3-58-16	Qv	9,563	-
	Luster	B1-55-27	Kp	193,001	87,581
	Maple	B5-60-[illegible]	Qd	41	-
	McRae	B1-55-[illegible]	Qv, Kp	95,239	-
	Messex	B5-55-1	Qd, Kp	8,462	-
	Messex-West	B6-55-35	Kp	404	-
	Orchard	B4-60-9	Qv	747	250,529
	Park	B1-59-26	Qd	19,091	-
	Peterson	B2-56-20	Qd	59,173	-
	Rake	B4-60-26	Qv	21,680	3,235
	Regent	B2-57-6	Qv	5,574	-
	Sand River	B1-56-26	Qd	346,147	80,155
	Sawbuck	B2-58-8	Qd	13,080	-
	Sentry	B2-56-28	Qd	2,225	-
	Stage Coach	B2-56-34	Qd	844	-
	Timpe	B1-56-6	Qd	35,769	-
	Track	B5-59-30	Qv	4,156	-
	Trend	B5-60-35	Qv	460	-
	Vallery	B3-59-23	Qd, Qv	1,075	-
	Zorichak	B2-55-10	Kp	221,101	706,608
Washington	Camp Creek	B1-53-4	Tc	54	-
	Lobo	B3-54-26	Qd, Qv	19,025	-
	Lone Valley	B1-54-28	Tc	4,448	-
	Patrol	B1-54-2	Qd	1,374	-
	Rago-North	B1-54-14	Tc	271,075	-
	Ranchero	B2-53-32	Qd	35,943	-
	Ruby	B2-54-28	Qd, Tc	75,752	-
	Shears Draw	B1-54-15	Qv, Tc	14,793	-
	Spar	B1-54-34	Tc	208,579	-
	Tarn	B1-53-31	Tc	10,555	-
	Topaz	B1-54-15	Tc	36,248	-
	Xenia-North	B2-53-7	Qd	48,455	-
	Xenia-West	B2-54-2	Qd	757,344	-

APPENDIX D
(Continued)

County	Field Name	General Location (T-R-Sec)	Geologic Formation Exposed at Land Surface [a/]	Associated Water Produced (Barrels) [b/]	Injected Water (Barrels) [c/]
Weld	Battle Canyon	B11-56-22	Tc, Tw	2,301	294,181
	Black Hollow	B7-66-6	Kl	734,450	1,566,502
	Border	B12-56-33	To	461	-
	Bounty	B8-57-36	Tw	25,447	-
	Buckingham	B8-59-33	Tw, Kl	945	-
	Cotton Valley	B9-56-17	Tw, Kp	13,409	-
	Flag	B7-58-35	Qu, Kl, Kf	2,000	-
	Greasewood	B6-61-24	Qu, Kf	1,846	222,288
	Greasewood-South	B6-61-35	Qu, Qd, Kf	380	-
	Indian Cave	B11-56-5	To	43,234	-
	Jasper	B12-57-28	To	32,471	-
	Keota	B9-61-4	Tw, Kl	80,235	82,239
	Loam	B7-58-31	Qu, Kl	3,232	-
	Mantle	B11-56-20	To	trace	-
	Maverick	B7-61-36	Kl	360	-
	New Raymer	B7-58-2	Kf	50,360	-
	New Windsor	B7-67-26	Qv,Kl,Kf	14,422	-
	Pierce	B8-66-23	Qv, Kl	152,134	356,933
	Riverside	B5-61-19	Qd	375	-
	Roggen-SW	B2-63-22	Qv	2,084	475,589
	Rush Creek	B11-56-1	To, Tw	1,417	-
	Stoneham-South	B8-56-17	Tw	13,869	-
	Tampa	B2-63-19	Qd	172	-
	Vim	B11-58-16	Tw	84,560	-
	Voltage	B7-57-2	Tw	10,424	-
	White Butte	B8-56-26	Tw	142,175	-
	Wild Horse	B7-58-9	Kl	35	-
	Wrangler	B10-56-26	Tw	9,787	-
	TOTAL			26,989,617	

a/ Geologic Formation: Qu - Unmapped Unconsolidated Deposits; Qd - Dune Sand; Qv - Valley-fill Deposits; To - Ogallala; Tw - White River Group; Tc-Chadron; Kl-Laramie; Kf-Fox Hills Sandstone; Kp - Pierre Shale.

b/ 42 gallons per barrel.

c/ Consists of associated water produced in a field and may include water from other sources such as associated water imported from other fields or water obtained from water-supply wells.

GPO 839-291